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Options for In Situ Capping of Palos Verdes Shelf Contaminated Sediments

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Preface

This report describes the results of a study of In Situ Capping Options for Palos Verdes Shelf Contaminated Sediments. The study was conducted by the U.S. Army Corps of Engineers (USACE) Waterways Experiment Station (WES) for Region 9 of the U.S. Environmental Protection Agency (EPA) under Interagency Agreement No. DW96955287-01-0, dated 15 September 1995. EPA Region 9 project manager was Mr. Frederick Schauffler.

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In-house WES technical review of this report was provided by Dr. Robert M. Engler, Senior Scientist, EL, and Mr. Norman R. Francingues, Chief, Environmental Engineering Division (EED), EL.

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This study was performed under the direct supervision of Mr. Norman R. Francingues, Chief, EED, and under the general supervision of Dr. John Harrison, Director, EL, and Dr. John W. Keeley Assistant Director, EL. COL Robin R. Cababa was Acting Director of WES.

Executive Summary

The U.S. Army Engineer Waterways Experiment Station (WES) has performed an evaluation of in situ capping options for sediment restoration of DDT and PCB contaminated sediments on the Palos Verdes (PV) shelf off the coast of Los Angeles, California, for Region 9 of the U.S. Environmental Protection Agency. In situ capping refers to placement of a covering or cap of clean material over an in situ deposit of contaminated sediment.

This study included prioritizing areas of the PV shelf to be capped, determining an appropriate cap design or designs, developing an equipment selection and operations plan for placement of the cap, developing a monitoring plan to ensure successful cap placement and long-term cap effectiveness, and developing preliminary cost estimates.

The primary functions of an in situ cap for the PV shelf would be physical stabilization of the contaminated sediment to retard suspension, reduction of bioaccumulation and movement of contaminants into the food chain, and reduction of the flux of dissolved contaminants into the water column. Two capping approaches were considered for selected areas of the shelf: (1) placement of a thin cap which would isolate the contaminated material from shallow burrowing benthic organisms, providing a reduction in both the surficial sediment concentration and contaminant flux, and (2) placement of an isolation cap which would be of sufficient thickness to effectively isolate benthic organisms from the contaminated sediments, prevent bioaccumulation of contaminants, and effectively prevent contaminant flux for the long term.

There are several potential sources of capping materials, including dredged material from the Queen's Gate navigation deepening project and borrow sites. The capping material would likely be a mixture of fine sand, silt, and clay. Evaluations focusing on erosion processes, seismic stability, bioturbation, consolidation, and cap effectiveness for control of contaminant flux were performed to determine appropriate cap designs.

The erosion and seismic evaluations indicated that the shelf area lying between the 40- and 70-m depth contours could be capped without the need for special control measures. Two separate capping prisms were evaluated; one, designated prism A, comprising approximately 4.9 km^2 was centered over the "hot spot", and the second, prism B, comprising approximately 2.7 km^2 was located northwest of the "hot spot."

The bioturbation, consolidation, and cap effectiveness evaluations indicated that a thickness of 15 cm was appropriate for the thin capping approach, while a thickness of 45 cm was found to be adequate for an isolation cap design. Capping prisms A and B with an isolation cap of 45 cm results in a reduction in potential exposures over the total shelf area on the order of 85 percent, while capping A and B with a 15-cm thin cap reduces the potential exposures on the order of 75 percent. Capping prism A alone with a 15-cm cap reduces the potential exposures on the order of 65 percent.

Hopper dredges are recommended as the equipment of choice for capping on the PV shelf because they are the most likely type of equipment used to deepen and maintain the navigation channels in Los Angeles/Long Beach harbor. Also, placement by hopper dredge would result in less potential for resuspension of the contaminated sediment as compared with placement of mechanically dredged material by barges. An evaluation of cap placement methods indicated that conventional placement of Queen's Gate material using a series of discrete releases along a system of placement lines or lanes would easily build up the required cap thickness. Hopper dredge spreading techniques can be used to construct the cap with materials from the borrow areas. The preferred sequence of placement of material can be defined by a series of cap placement cells, beginning with the southeasternmost cell and progressing in order to the northwest. Such a sequence would result in the lowest potential for recontamination of the cap surface from adjacent areas since the prevailing currents are from southeast to northwest.

Considering the two possible capping approaches of a thin cap or an isolation cap and two capping prisms, A and B, three representative capping options were defined:

Option 1 - cap prism A and B with a 45-cm isolation cap over 7.6 km^2
(approximate cost $41.6M to $66.9M)

Option 2 - cap prism A and B with a 15-cm thin cap over 7.6 km^2
(approximate cost $17.2M to $28.6M)

Option 3 - cap prism A with a 15-cm thin cap over 4.9 km^2
(approximate cost $11.8M to $19.2M)

Option 1 would require on the order of 7 million cubic meters of cap material and would require approximately 3 years to construct with a single hopper dredge. Options 2 and 3 would require proportionally less material and less time. Construction time could be shortened by using multiple hopper dredges. Additional options for cap thickness and area could also be considered.

Monitoring is required to ensure that the cap is placed as intended and that the cap is performing the desired functions of physical isolation and reduction of contaminant flux. The monitoring program should focus on cap thickness, cap

benthic recolonization, and physical and chemical characteristics of the cap over time. The principal monitoring approaches should include subbottom acoustic profiling, sediment core sampling, biological sampling, and sediment profile camera images.

The overall conclusion from the study is that in situ capping is a technically feasible alternative.

1 Introduction

Background

The U.S. Army Corps of Engineers (USACE) Waterways Experiment Station (WES) has performed technical studies for the National Oceanic and Atmospheric Administration (NOAA) in support of the Southern California Natural Resources Damage Assessment (Palermo 1994). These studies focused on evaluation of sediment restoration alternatives for DDT- and PCB-contaminated sediments on the Palos Verdes Shelf[1] off the coast of Los Angeles, California. The project location is shown in Figure 1.

A number of options for restoration were evaluated in the NOAA studies. One alternative, which does not involve removal of the sediments, was in situ capping (ISC) with clean materials. An initial determination of the feasibility of ISC was made as a part of the overall evaluation of options for sediment remediation performed for NOAA. The NOAA study concluded that in situ capping is a technically feasible alternative.

Region 9 of the Environmental Protection Agency (EPA) is now considering response options for the site under its Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) authorities. EPA Region 9 has completed a screening evaluation of response actions that identified institutional controls and in situ capping as response actions which satisfied screening criteria (EPA 1997). Region 9 has requested WES technical support in conducting the necessary engineering and environmental analyses to determine the feasibility and effectiveness of in situ capping. An Engineering Evaluation/ Cost Analysis (EE/CA) will be prepared by EPA Region 9 to serve as the primary basis on which to determine the need for action and the feasibility of options.

[1] For purposes of this report, the term “Shelf” refers to areas of the continental shelf and slope evaluated for potential sediment remediation, while the term “shelf” refers to those areas on the continental shelf only.

Objective and Scope

The objective of this study is to evaluate options for in situ capping on the Palos Verdes Shelf for remediation of contaminated sediments. This effort includes prioritizing areas on the shelf to be capped, determining appropriate cap designs, developing an equipment selection and operations plan for placement of the cap, developing preliminary cost estimates, and developing a monitoring plan to ensure successful cap placement and long-term cap effectiveness. The USACE has developed guidelines for dredged material capping (Palermo et al. 1998) and in situ capping of contaminated sediments for purposes of remediation (Palermo et al. 1996). These guidelines were applied in conducting this study.

The main body of this report is intended to present the major findings of the study. The evaluation includes definition of design functions for the in situ cap, description of the pertinent site and sediment characteristics, cap designs, cap placement evaluation and operations plan, monitoring and management considerations, and preliminary cost estimates. Appendices to this report contain more detailed information: Appendix A - Erosion Evaluation; Appendix B - Seismic Evaluation; Appendix C - Consolidation Analysis; Appendix D - Cap Effectiveness Modeling; Appendix E - Cap Placement; Appendix F - Monitoring and Management; Appendix G - Cost Estimates; and Appendix H - Sediment Profile Data.

Description of In Situ Capping

In situ capping refers to placement of a covering or cap of clean material over an in situ deposit of contaminated sediment. The in situ capping options evaluated in this study involve transporting cap materials to the shelf and placing the materials in such a way that they form a subaqueous cap over the contaminated sediments. The area on the shelf with DDT concentrations greater than 1 ppm is in excess of 14 km^2. [1] However, the majority of the mass of DDT is within a much smaller area.

Since contaminated sediments are present on the shelf and slope over a very large area, an in situ capping remediation approach would likely involve capping areas with higher contaminant exposure as a first priority. Areas of lower exposure might be capped at a later date as capping material becomes available. The overall remediation could therefore be carried out in a staged fashion.

[1] In accordance with standard USACE practice, SI units (metric system) are the primary units for this report. However, some U.S. units are used because several of the numerical models used in the study are constructed using only customary units. Customary units are also commonly used by the dredging industry in the United States. However, where appropriate, the metric equivalent will be provided.

This approach differs in its philosophy from the concept of capping as described in the previous NOAA studies. The NOAA studies focused on a one-time remediation construction effort which would be designed at a conservative level such that the entire contaminated area on the shelf was restored and minimal future maintenance of the project would be required. This resulted in a proposed design calling for a thick cap over a very large area with special “rock ribs” for maintaining the required cap thickness in the event of a major seismic event (Headland et al. 1994). The philosophy under the EPA Superfund removal[1] response process is different. This study therefore focused on developing a number of in situ capping options which would result in significant short term reduction in risk to human health and the environment.

Although a number of potential sources of capping material exist, navigation dredging projects present an opportunity to beneficially use dredged material to cap the most critical areas on the shelf. Alternatively, some or all of the necessary volume of capping material could be taken (dredged) from a nearby borrow area in order to ensure construction of the cap within the desired time frame.

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[1] The term “removal” in this context does not refer to the physical removal of the contaminated sediments.

2 Site Characterization

Setting

The project setting has been described in Palermo (1994) and Lee (1994). The project area is within the Southern California Bight, which consists of a broad continental borderland of alternating deep basins and surfacing mountain ranges which form a series of offshore islands. The major area of interest is the Palos Verdes shelf and slope shown in Figure 2.

The Palos Verdes shelf and slope are located off the Palos Verdes peninsula which separates Santa Monica and San Pedro Bays. The shelf and slope are generally defined as the offshore area extending from Point Vicente southeast to Point Fermin. Three sewer outfall diffusers discharge onto the shelf approximately 3 km offshore of Whites Point in approximately 60 m of water.

The shelf varies in width from approximately 1 to 6 km and extends offshore to the shelf break at water depths of approximately 70 to 100 m. The bottom slope on the shelf generally increases with water depth, with slopes of approximately 1 to 2 deg at water depths of 30 to 70 m. The slope increases to approximately 6 to 7 deg at depths of 70 to 100 m. At the 100-m depth, the slope increases to 13 to 18 deg.

The native sediments of the shelf are comprised of silty sand. Since the first outfall diffusers became operational in 1937, particulate matter discharged through the outfalls has settled out and built up an effluent-affected (EA) sediment deposit on the shelf and slope. This EA deposit contains levels of organic matter and chemical contaminants higher than the native sediments and provides the focus of sediment restoration/ remediation efforts on the shelf and slope.

The EA deposit forms a band that extends from approximately the 30-m isobath offshore to water depths in excess of 400 m at a distance of approximately 3 to 4 km offshore and alongshore from Point Fermin to an area northwest of Point Vicente, a distance of 12 to 15 km (Figure 3 and Figure 4). The EA deposit

is absent from approximately the 30-m water depth shoreward because of the higher wave energy. The most contaminated sediments on the shelf occur as a lens approximately 10 to 30 cm below the sediment-water interface. On the slope, the zone of maximum contamination is closer to the sediment-water interface than on the shelf. Strong currents at the shelf break have resulted in a patchy, thin sediment layer with areas of bare rock. A detailed characterization of the shelf and slope has been prepared by Lee (1994).

The volume of the entire mapped EA layer has been estimated at approximately 9 million cubic meters, and the mapped layer covers a surface area of approximately 40 square kilometers. The volume of the contaminated sediment is large and well in excess of those volumes which would provide economies of scale for potential restoration/ remediation alternatives.

Evaluations made for NOAA (Palermo 1994) assumed that the entire effluent deposit on the shelf and slope would potentially be restored. However, given the different focus of the EPA Superfund program (allowing for an incremental approach), areas to be restored are prioritized as a part of this study.

Geographic Information System

A Geographic Information System (GIS) database was developed for the shelf and slope by the U.S. Geological Survey (USGS) (Lee 1994). WES acquired the GIS database from the USGS for use in this study. The GIS is used for spatial data integration and analysis, environmental characterization, visual portrayal of numerical modeling results and illustration of engineering design, and operational recommendations.

Sediment Characterization

Both the Los Angeles County Sanitation Districts (LACSD) and the USGS have conducted extensive physical and chemical characterization studies of the sediments. LACSD has conducted periodic sampling and characterization of the sediments as a part of the monitoring and reporting program for the Joint Water Pollution Control Plant point source discharge permit (LACSD 1996). The USGS conducted an integrated, multidisciplinary investigation of the continental shelf, slope, and basin adjacent to the Palos Verdes Peninsula as a part of the NOAA studies (Lee 1994). One of the major goals of the USGS study was to map the distribution of total DDT[1], PCBs[2], and other chemical and physical properties in the sediment. The distribution of the contaminants as defined by the

[1] For purposes of this report, unless otherwise stated, DDT refers to total DDT to include DDT, DDE, and all its isomers and metabolites.

[2] For purposes of this report, unless otherwise stated, PCB refers to total PCB to include all PCB congeners.

USGS (Lee 1994) was used in the evaluations in this study because it represents a more comprehensive characterization of the larger area comprising the shelf and slope and defines the sediment vertical profile in a more detailed fashion at more stations than the LACSD studies. The following description of the sediment characterization was condensed from Lee (1994).

A variety of instruments and sampling approaches were used to characterize the EA deposit and surrounding areas including a very high-resolution seismic-reflection profiler (chirp sonar), a high-resolution seismic-reflection profiler; a bathymetric profiler; and a sidescan sonar. Sediment samples were taken with vibracorer, gravity corer, and box corer. The majority of the samples were taken with a standard NEL box corer which has a surface area of 20 cm by 30 cm and can penetrate up to 60 cm. The locations of the box core stations are shown in Figure 2.

Core samples were tested for total DDT, DDE, PCBs, and total organic carbon (TOC) content using 2- or 4-cm core increments. Appendix H summarizes the properties of the EA sediment layers for each station (Lee 1994). Individual 2- and 4-cm increments from the USGS cores were grouped into layers based on logical breaks or changes in sediment density, TOC, PCB, or total DDT as indicated in Appendix H, and these sediment properties were used in the subsequent analyses in this report. A profile of total DDT is given for a typical alongshore cross section in Figure 3. A map of the maximum total DDT at any 4-cm increment is given in Figure 4. The distributions of p,p'-DDE, total DDT, total PCBs, and TOC show similar patterns. The zones of highest concentration extend from slightly southeast of the outfall pipes to several kilometers northwest of the pipes. The highest concentrations are typically centered on the 60-m isobath.

The total volume of the EA deposit is approximately 9 million cubic meters, with 70 percent of this volume present on the continental shelf in water depths less than 100 m and the remainder present on the continental slope. Association of the sediment body with effluent discharged from the outfall is illustrated by high concentrations of organic carbon (to as much as 9 percent), increased thickness and contamination levels near the outfalls, and the presence of a sediment delta immediately off the outfall.

Virtually all of the EA sediment deposit is contaminated with DDT and PCBs. The total mass of p,p'-DDE in the EA deposit is greater than 67 Mg (metric tons). About 75 percent of this total mass is present on the shelf, and the remainder is present on the slope.

The EA sediment deposit is characterized by a lower bulk density and finer grain size than the native sediment deposited before the outfalls were constructed. The sediment is very soft, but not anomalously so in comparison with muddy

marine sediment found elsewhere in the world. Bottom photographs and videos show the sediment on the shelf to be biologically reworked throughout the study area. In water depths less than 50 m, the shelf shows evidence of physical reworking as well. The upper slope is also biologically reworked, but less intensively than the shelf. Blocks of failed sediment, characteristic of landslide deposits, were photographed on the slope and observed in acoustic profiles.

Hydrodynamics

Waves

Compared with other coastal areas in Southern California, the area off the Palos Verdes Peninsula has a relatively mild wave climate, primarily due to the sheltering effects of the offshore islands, with Santa Catalina and San Clemente providing protection from waves approaching from the south. Waves are most severe in the winter (Dec-Mar) and mildest in the summer and early fall (Jul-Oct). Mean wave heights are 1.0 m, with significant waves heights greater than 1.0 meter occurring only 45 percent of the time and wave heights greater than 1.5 m occurring only 18 percent of the time. Higher waves generally approach from the west, southwest, and southeast.

Currents

Subsurface currents on the shelf are generally low. During fair weather, they range from 7-10 cm/sec, with maximum alongshelf currents of 40 cm/sec and cross shelf currents of 20 cm/sec. The exception is a potentially strong northwesterly flowing current at a depth along the base of the slope that can reach velocities of up to 60 cm/sec during storms. Surface currents are most likely wind and wave dominated and are unlikely to be strong except during storms. Mean surface currents on the shelf are less than 5 cm/sec (LACSD 1996).

Outfalls

The ocean outfall pipes are laid on the ocean floor (i.e., not elevated) and are ballasted about halfway up the pipe. There are two primary outfalls in use continually, a 90-in. pipe and a 120-in. pipe. The diffuser ports are located about 3 ft off the ocean floor on the side of the pipes. There are also two outfalls that are used intermittently, a 72-in. pipe used in the winter and a 60-in. pipe used every few years. LACSD recently advertised for outfall repairs (reballasting). Bid documents indicated a buildup of grit mounds near the end of the pipes. There are potential concerns regarding the effect of a cap on the outfalls.

Reballasting will likely involve placement of rock cover piled above the level of the ports, except immediately at the ports, that would be cleared. [1]

Groundwater Flow Conditions

The potential for general groundwater flux upward through the contaminated sediment layer should be considered in the design of an in situ cap. The contaminated areas on the PV shelf lie offshore at distances up to several kilometers. Due to the great distance offshore, groundwater flow would not normally be a concern, with the possible exception of isolated springs or seep areas.

Well monitoring has been conducted at Portuguese Bend, and permeability measurements were made in the area.[2] There was no evidence of any groundwater flow offshore, and all seeps are nearshore and are due to basalt intrusions. Most unweathered bedrock is impermeable except along minor faults and fractures in brittle rocks. The bentonite beds tend to be nearly perfect aquicludes such that groundwater is generally restricted to the weathering zone. In areas where basalt is exposed onshore, water gains access to the geothermal systems that transport the water to the ocean. Flow from springs occurs in several areas along the coast, such as at Whites Point. Most springs are within the surf zone between high and low tide lines. The Palos Verdes Peninsula is a doubly plunging anticline. Wave erosion has cut more deeply into the stratigraphy in the onshore area than the offshore area. Consequently, overburden thickness generally increases in the offshore direction, and loss of fluid pressure in excess of sea water pressure is more likely to occur in the near shore area than the offshore area.[2] Based on this information, no further evaluation of groundwater flow as a potential general upward flux through a capped layer was considered warranted at this time.

Seismic Conditions

Southern California is a seismically active area. This has implications for cap design and siting considerations. The potential for liquefaction and flow of the existing EA sediments, underlying native sediments, as well as a potential cap in the event of a major earthquake must be appropriately evaluated.

A conceptual assessment of the potential impact of earthquakes on stability of the capped sediment was conducted as a part of the NOAA studies (Headland et al. 1994). This assessment concluded that very low values of residual shear

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[1] Personal Communication, 22 July 1997, Bob Horvath, Technical Services Department, LACSD.

[2] Personal Communication, 5 May 1997, Dr. Perry Ehlig, professor emeritus, California State University, Los Angeles.

strength in the sediments during a seismic event would be available to prevent a flow-type failure and recommended construction of rock ribs to retain the capping materials. This assessment also indicated the need for more detailed analyses. A more detailed evaluation of seismic considerations was conducted as a part of this study (Chapter 3).

Control of Contaminant Sources

Source control is normally considered a requirement prior to initiation of sediment remediation. The sources of DDT and PCB contamination to the PV Shelf through the ocean outfall pipes have been essentially eliminated (LACSD 1996).

3 In Situ Cap Design

Design Requirements and Objectives

For the PV Shelf, the major processes influencing the movement of contaminants into the environment are the flux of contaminants to the water column by biodiffusion and molecular diffusion and the bioaccumulation of contaminants by benthic organisms with subsequent movement into the food chain.

Therefore the primary functions of an in situ capping option for the PV shelf defined for this study are:

a. physical isolation of the contaminated sediment from the benthic environment, reducing the exposure of organisms to contaminants and the potential bioaccumulation and movement of contaminants into the food chain,

b. reduction of the flux of dissolved contaminants into the water column, and

c. physical stabilization of the contaminated layer to retard resuspension due to currents and waves.

Considering these functions, two capping approaches were defined:

a. Thin cap - a cap of sufficient thickness to isolate the contaminated material from shallow burrowing benthic organisms (by far the majority of the organisms), providing a proportional reduction in the exposures and the flux of contaminants into the water column.

b. Isolation cap - a cap of sufficient thickness to effectively prevent contaminant flux for the long term, isolate benthic organisms from the material, and prevent bioaccumulation of contaminants.

These two approaches could be used in combinations, with placement of the thicker and thinner design cap thicknesses over selected contaminated areas to provide an optimized level of isolation and exposure reduction. Both the thin cap and the isolation cap would also serve to physically stabilize the sediments and retard resuspension. A conceptual illustration of a thin cap and an isolation cap, showing the relative level of bioturbation is shown in Figure 5.

Capping Materials

A capping sediment or material must be one which is acceptable for open water disposal (i.e., a "clean" sediment). The evaluation for open water disposal acceptability for capping material placed on the PV Shelf would be accomplished using appropriate techniques under Section 404 of the Clean Water Act (EPA/USACE 1998) since the material placement would be for purposes other than disposal. Physical characteristics of the capping sediment are also of particular interest in capping design. Density (or water content), grain size distribution, and cohesiveness of the capping sediment must be evaluated. Previous studies have shown that both fine-grained materials and sandy materials can be effective capping materials from the standpoint of isolation (Brannon et al. 1985).

The source of capping material used in a capping project may be a matter of choice. Sediment taken from areas which also require dredging presents definite economic advantages. The U.S. Army Engineer District, Los Angeles (CESPL) conducted a survey of potential capping materials for the NOAA study (Welch 1993). The survey identified several candidate sources of capping material including dredged material from navigation projects in the region, subaqueous borrow material, upland quarry/borrow material, debris, manufactured materials, soil from the Portuguese Bend landslide, and material excavated from wetland creation projects.

Additional information on the availability of materials from navigation dredging projects and from borrow areas was considered for this evaluation. Summary descriptions of the most likely capping material sources follow.

Dredged material

The Los Angeles District has identified three possible sources of material from either new work or maintenance dredging within the LA region. The prospective sources include the Queen’s Gate harbor entrance channel, Upper Newport Bay, and City of Newport. The volume of maintenance dredging in the harbors is only about 50,000 yd^3 per year, therefore maintenance dredging is not a sufficient source of capping material. Channel deepening and improvement projects (referred to as new work projects) will generate larger volumes.

Approximately 6 million cubic yards of material will be dredged from the Queen's Gate entrance channel (see channel location in Figure 6) to deepen and improve the channel (new work dredging), and this project has been identified as a potential capping material source. The Queen's Gate dredging was scheduled to begin in the summer of 1998 and to be conducted over an 18-month period. The dredged material from this project was to be placed at ocean disposal sites, in existing borrow pits within the harbor, and in an old anchorage area within the harbor (West Anchorage Disposal Site in Figure 6). Approximately 3 million yards of the material was to be placed within the anchorage area, and this material could potentially be removed later from the anchorage area and used as capping material. Depending on the timing, some of the Queen's Gate material could be available for use as capping material during the timeframe of the new work dredging project. [1]

Subaqueous borrow

Evaluation of potential subaqueous borrow areas focused on areas previously mined for sand and gravel within the shelf or areas within reasonable transport distance. A large area is located offshore of Anaheim Bay, Orange County, California (State of California 1983). The Los Angeles District is initiating studies for new borrow areas offshore at Oceanside and Carlsbad, San Diego County, California. The Santa Monica Bay area is also being evaluated for sites for medium- to coarse-grained sand for a capping project in Marina del Rey.

Potential sources of offshore sand and gravel are located outside the Los Angeles/Long Beach breakwaters (State of California 1983). These areas are designated as A-I through A-V as shown in Figure 6 and collectively contain over 200 million cubic yards of sand. Headland et al. (1994) reviewed this information and concluded that the material in Area A-III was well suited for use as cap material and used this source as a basis of cost estimates prepared for the NOAA studies.

Representative Cap Material Properties

The properties of the available cap materials are varied, and final selection of capping materials for specific capping scenarios would depend on more detailed evaluations. However, it is assumed for purposes of this study that the available capping materials would be sandy sediments with a fraction of fine silt/clay. The Queen's Gate dredging project and borrow areas A-II, A-III, and A-IV were considered as potential sources of capping materials for evaluations in this study.

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[1] Personal Communication, 26 May 1998, Anthony Risko, Civil Engineer, CESPL.

The Queen’s Gate material is composed of approximately 50 percent sand, 40 percent silt, and 10 percent clay. The mean grain size of the Queen’s Gate material is approximately 0.1 mm. The mean grain sizes of sand from borrow areas A-II, A-III, and A-IV are 0.22, 0.27, and 0.24 mm, respectively (Headland et al. 1994).

Direct release from hopper dredges is the suggested placement method for the cap (Chapter 4). The water depths at the site and the method of release would result in the material’s settling through the water column and a gradual buildup of the cap due to multiple releases from the hopper dredge.

Required Cap Thickness

The composition and dimensions (thickness) of the components of a cap can be referred to as the cap design. This design must address the need to physically isolate the contaminated sediments from the benthic environment and control potential flux of contaminants through the cap. The design must also be compatible with available equipment and placement techniques. For this evaluation, the design effort focused on the required thickness of granular cap material (dredged material or sediment) to achieve the desired functions of the cap. Erosion and seismic evaluations indicated that special control measures or cap design components, such as armor layers or rock ribs for seismic stability, were not needed for caps placed between the 40- and 70-m depths.

Determining the appropriate cap thickness depends on the physical and chemical properties of the contaminated and capping sediments, hydrodynamic conditions such as currents and waves, potential for bioturbation of the cap by benthic organisms, potential for consolidation of the cap and underlying sediments, and operational considerations. Total thickness is normally composed of components for bioturbation (i.e., physical isolation), consolidation, erosion, operational considerations, and chemical isolation.

Early technical guidance on determination of cap thickness for dredged material capping projects was based on empirical studies of isolation effectiveness (Brannon et al. 1985) and conservative interpretation of erosion and bioturbation requirements (Palermo 1991). Application of the earlier guidance frequently resulted in design cap thicknesses on the order of 1 ft for isolation, 1 - 2 ft for bioturbation, plus allowances for any potential erosion. More recent guidance on design of both dredged material caps and in situ caps calls for a more precise analytical evaluation of the necessary cap thickness components (Palermo et al. 1996, 1998). These more precise methods, including application of computer models for erosion and contaminant flux evaluations, were used to determine the necessary cap thickness components for this study.

The design sequence used for determining appropriate cap thicknesses for this study was:

a. Conduct a detailed erosion evaluation, considering both ambient currents and episodic events such as storms.

b. Conduct a detailed evaluation of seismic stability of a capped deposit.

c. Assess the bioturbation potential of benthos and determine an appropriate cap thickness component for bioturbation.

d. Evaluate potential consolidation of the cap material and underlying contaminated sediments.

e. Evaluate operational considerations and determine restrictions on cap thickness placement.

f. Evaluate the potential for short term and long term flux of contaminants through the cap and determine any necessary additional cap thickness component for chemical isolation.

The results of each of these evaluations are summarized below.

Erosion Evaluation

Methods for analysis of sediment transport are available to evaluate erosion potential. These methods can range from simple analytical techniques to numerical modeling. One model for evaluation of the long-term fate of a mound or deposit (i.e., stability over periods ranging from months to years) is the USACE Long Term FATE (LTFATE) model. This model considers both the erosion and consolidation processes for a defined modeling grid. Hydrodynamic conditions at a site are considered using simulated databases of wave and current time series. These boundary conditions are used to drive coupled hydrodynamic, sediment transport, and bathymetry change models.

An evaluation of in situ cap stability for conditions on the shelf was conducted using a 1994 version of the LTFATE model (Scheffner 1991a, b) as a part of the NOAA studies (Headland et al. 1994). This analysis indicated that a sand cap would be stable for most conditions but could experience erosion over portions of the cap during severe storm events.

An evaluation of erosion was conducted for this study using a revised and refined version of LTFATE (Scheffner 1996, Scheffner et al. 1995). The model was applied as a screening tool to define areas where erosion would be a factor in cap design and/or where capping would not be recommended due to erosion

potential without including special control measures in the design. The detailed results of this evaluation are presented in Appendix A.

A model grid over the entire shelf would be computationally unworkable, therefore the LTFATE model was used to simulate erosion over defined model grids of 1 by 4 and 2 by 2 km located in water depths from 30 to 100 m. Three representative capping materials were modeled: 0.3-mm sand, 0.1-mm sand, and cohesive silt and clay.

Several approaches were used in defining the wave conditions for the model runs: full statistical year calculations were performed, the five largest storms (as determined by maximum wave height) from the 20-year (1956-1975) Wave Information System (WIS) Southern California hindcast were simulated, and, finally hypothetical events with maximum wave heights of 5.5 and 7.0 m were simulated. The wave/current/stage height database was developed as described by Scheffner (1996) except in this case for the West Coast. Tidal and storm surge databases were generated using the ADCIRC finite element hydrodynamics model (Luettich, Westerlink, and Scheffner 1992). ADCIRC was designed to model large computational domains and has been calibrated and verified for the West Coast (Allard et al. 1996). A detailed description of the modeling approaches and results is presented in Appendix A.

Comparative results of the LTFATE modeling are graphically illustrated in Figure 7 which shows the total erosion versus water depth for a hypothetical severe storm event generating a 5.5-m wave height for silt/clay, 0.1-mm sand, and 0.3-mm sand capping materials. The only significant erosion for the sand cap materials occurs in water depths shallower than 40 m. Caps composed of silt and clay materials are more subject to erosion. Based on these results, capping with fine sandy materials in water depths less than approximately 40 m would require consideration of additional cap thickness to offset potential storm induced erosion. Since the cap design for this project is focused on an incremental capping approach to include consideration of a thin cap option, capping in water depths of less than about 40 m is not recommended. Further, use of only silt/clay material for capping is not recommended. No cap thickness component would be required for erosion for water depths exceeding about 40 m if sandy cap material was used. Fortunately, the contaminant concentrations in the EA sediments evident between the 30-m and 40-m depth contours are very low compared with these in the portion of the shelf between 40 m and the shelf break. Also, fortunately, the available capping materials identified thus far are predominantly fine sandy materials.

Areas above the 40-m depth contour could be considered for capping, but control measures to resist potential erosion would have to be included in the design. Such measures might include use of a coarser cap material (such as a coarse sand) or periodic replenishment of cap material following major storm events.

Seismic Evaluation

Seismic stability must be considered in the cap design. If liquefaction occurs, the shear strength of the material is temporarily reduced, and the residual shear strength during liquefaction provides the resistance to flow. Bottom slope is also a major factor in the assessment of potential flow failures due to earthquakes and can be used to define areas for which capping would not be feasible without special control measures.

An evaluation of seismic considerations was therefore conducted for this study (Appendix B). The field and laboratory investigations reported by Lee and McArthur (1995) provided data from which the steady-state and residual shear strengths for the Palos Verdes sediments were estimated. Analyses were performed to estimate the seismically induced shear stresses that might occur in the cap and contaminated sediments. The USACE WESHAKE program, which is a one-dimensional, equivalent linear wave propagation code, was used (Schnabel, Lysmer, and Seed 1972, Sykora et al. 1994) The material properties of the underlying sediments were estimated from data provided by Richard Wittkop (Port of Los Angeles 1992) and the WES shear wave velocity database (Sykora 1987).

The results of this evaluation indicated that, for existing conditions (i.e., without a cap), the contaminated sediments on slopes of up to 5 deg are not susceptible to flow failure if subjected to moderate earthquakes (magnitude 5.5 or greater). However, on the steeper slopes, the existing sediments are susceptible to flow failure under existing conditions.

Addition of a cap with thickness up to 60 cm (approximately 2 ft) will not render the contaminated sediments susceptible to flow failure on slopes of 5 deg or less. However, addition of a cap of any thickness on slopes of 11 deg or greater will be susceptible to flow failure. Even though cap materials and sediments may liquefy during moderate to strong shaking (magnitude 5.5 or greater with a cap thickness of 1 ft or greater), they would be expected to restabilize after lateral deformations on the order of 3 ft or less (on slopes of 5 deg or less).

Based on the results of this evaluation, areas of the site with bottom slopes less than 5 deg are suitable for capping from the standpoint of seismic considerations, but areas with bottom slopes exceeding 5 deg should not be considered for capping. The bathymetry of the shelf is relatively flat seaward, with slopes less than 2 deg, until the shelf break at a depth contour of 70 m, where the slopes increase to greater than 6 deg. Based on the distribution of slopes, areas deeper than the 70-m contour should not be considered for capping. A detailed description of the seismic evaluation is presented in Appendix B.

Potential Areas for Capping

The erosion and seismic evaluations indicated that the shelf area lying between the 40-m and 70-m depth contours could be capped without special controls or design features for erosion or seismic stability. Two separate capping prisms were therefore defined between those depth contours as shown in Figure 8. Prism A lies in the southeast portion of the EA deposit between the 40-m and 70-m contour. Prism B lies immediately to the northwest of prism A, with its boundaries encompassing the areas between the 40-m and 70-m depth contours.

The boundaries of prism A were determined based on the locations of the 40-m and 70-m depth contours corresponding to the erosion and seismic limitations, as described above, and the areal extent of the "hot spot" as defined by the 100 mg/kg sediment DDT concentration at depth. Prism A therefore represents the area with the highest relative DDT concentration that could be potentially capped and, logically, would be the area capped first if an incremental capping approach were implemented. The boundaries of prism B were determined based on the 40-and 70-m depth limitations and the areas adjacent to Prism A with areal extent of sediment DDT concentration at depth exceeding 20 mg/kg. Prism B represents the area of incremental contamination logically capped as a second increment if an incremental capping approach were implemented. Prisms A and B, with the highest relative contaminant concentrations also correspond to the areas with highest flux of contaminants (discussion follows). The total areas of prisms A and B are about 4.9 and 2.7 km^2, respectively, with the total of both prisms being approximately 7.6 km^2. Other areas on the shelf within the 40- and 70-m depth limitations could be capped in subsequent increments, but the relative benefit would be less than capping of prisms A and B.

Operations designed to cap prisms A and B (Chapter 4 and Appendix E) would result in thin layers of cap material accumulating in adjacent areas. This thin cap material layer would eventually be mixed with underlying sediments by bioturbation and would provide remediation benefits to these areas of lesser contamination, but such benefits were not considered in this study.

Bioturbation Evaluation

One function of a cap for the Palos Verdes Shelf is to physically isolate the contaminated material from benthic organisms. In addition to geotechnical and physical factors, the potential effects of bioturbation by organisms on cap integrity must be considered in the design of the cap.

There are many mechanisms whereby organisms influence the physical properties of sediments or move sediments or porewaters. Collectively, these mechanisms (e.g., burrow construction, maintenance irrigation, and ingestion and defecation of sediment particles) are bioturbation. The overall effects are

dependent upon behaviors of species comprising the benthic assemblages at a given site.

For purposes of this report, the following definitions are applicable:

a. Bioturbation - the disturbance and mixing of sediments by benthic organisms. In a general sense, bioturbation refers to the physical movement or mixing of sediment particles or porewaters due to a variety of processes associated with benthic organisms.

b. Sediment mixing - physical mixing of sediment particles due to bioturbation. For purposes of cap design and evaluation, a mixed sediment layer near the surface can be assumed to be completely and homogeneously mixed.

c. Biodiffusion - diffusion of materials, including contaminants, through the sediment column both vertically and horizontally as a result of biological activity. Biodiffusion rates enhance those rates accounted for strictly by abiotic processes. In the context of cap design, biodiffusion can be an important consideration even at sediment depths below the surficial layer of intensively bioturbated sediments.

The vertical distribution and movements of organisms within the sediment column are important if their behaviors expose them to contaminated sediments, particularly if exposure opens pathways for bioaccumulation and transfer to higher trophic levels. Likewise, depending on characteristics of ambient sediments and those used to cap the site, organisms that colonize a cap could affect sediment cohesion and stability. The depth to which organisms bioturbate is of greatest concern, however, because if the cap were sufficiently thin, sediment mixing could threaten the cap's primary function, which is physical isolation of contaminants.

Aquatic organisms that live on or in bottom sediments can greatly increase the movement of contaminants (solid and dissolved) through direct translocation of sediment particles (e.g., by ingestion at depth and defecation at the surface) or porewaters (e.g., by irrigation of burrows), by increasing the surface area of sediments exposed to the water column (e.g., walls of burrows or feeding voids), and by serving as food for epibenthic or demersal organisms grazing on the benthos. The specific assemblage of benthic species that recolonize the site, the bioturbation depth profile, and the abundances of key organisms (e.g., very efficient sediment mixers or deep bioturbators) are major factors in determining the degree to which bioturbation will influence cap performance.

The depth to which bioturbation occurs can be highly site specific, reflecting dependence on behaviors of specific organisms and the characteristics of the substrate (i.e., grain size, compaction, organic content, porewater

geochemistry, etc.). However, certain generalizations can be made. The colonization process, as relevant to capping issues, has been reviewed by Rhoads and Carey (1996). Initial “stage I” colonization of dredged material caps in coastal environments by benthic macroinfauna is primarily by small-bodied polychaetes (spionids and capitellids) and bivalve molluscs, followed by “stage II” organisms, frequently amphipods, that often create dense tube mats forming a thin veneer at the sediment/water interface. Although stage I and II organisms tend to have a net stabilizing effect on surficial sediments, they do not mix sediments beyond a depth of several centimeters. Initial pioneering assemblages tend to persist for several months to 2 years, but are gradually replaced by deeper penetrating, larger bodied infauna. Early colonizers also tend to be predominantly surface deposit feeders, whereas later arrivals, particularly “stage III” infauna, tend to feed in a head-down position at sediment depths approaching 30 cm.

The intensity of bioturbation is predictably greatest at the sediment surface and generally decreases with depth. Three descriptive zones of bioturbation are of importance: surficial, middepth, and deep (Figure 9). Over time following colonization, the surficial layer of sediment will be effectively overturned by shallow bioturbating organisms, and can be assumed to be a continually and completely mixed sediment layer for purposes of cap design. This uppermost sediment layer is generally a few centimeters in thickness. Depending on the site characteristics, mid-depth penetrating organisms recolonize the site over time. The intensity of bioturbation activity for these organisms will generally decrease with depth as shown in Figure 9. The species and associated behaviors of organisms which occupy these surface and mid-depth zones are generally well-known on a regional basis. There may also be potential for colonization by deep-penetrating organisms (such as certain species of mud shrimp) which may borrow to depths of 1 meter or more. However, knowledge of the occurrences and behaviors of these organisms is very limited. The cap design criteria recommended herein assume that deep bioturbators will not colonize the site in densities sufficient to compromise cap integrity.

Cap thickness required to accommodate bioturbation was determined for the PV shelf cap design based on the known behavior and depth distribution of infaunal organisms likely to recolonize the site in significant numbers. In February 1997 the EPA and WES convened a panel that included individuals with knowledge relevant to bioturbation in the region of the Palos Verdes Shelf:

Janet Stull	Los Angeles County Sanitation Districts (LACSD)
Mary Bergen	Southern California Coastal Water Research Project (SCCWRP)
Joe Germano	EVS Consultants
John Lindsay	National Oceanic and Atmospheric Administration
John Cubit	National Oceanic and Atmospheric Administration
Douglas Clarke	USACE Waterways Experiment Station

The panel reviewed the available information on fauna likely to colonize the site once a cap was in place.

Fortunately, extensive monitoring of benthos in the Palos Verdes Shelf area by the Los Angeles County Sanitation Districts[1] provides an excellent database upon which to base general estimates of bioturbation processes, including depth of sediment mixing. Results of pertinent studies have been published in a series of papers (Stull et al. 1986, Stull, Irwin, and Montagne 1986, Stull, Swift and Niedoroda 1996a, b, c; Niedoroda et al. 1996) that describe bioturbation issues related to the Palos Verdes Shelf ecosystem.

The majority of benthic organisms inhabiting the proposed project area are "shallow" bioturbators that dwell in the uppermost 15 to 20 cm (and perhaps to 30 cm)[2] of the sediment column, within which sediment mixing largely occurs. Sediment mixing by other members of the benthic assemblages known to occur in significant numbers at least occasionally in the project area would extend the sediment depth to as much as 30 cm, although the rates of sediment mixing would be expected to be relatively low. This description of sediment reworking by benthos is consistent with that described for other coastal areas, as summarized by Rhoads and Carey (1996).

In certain coastal areas the bioturbation effects of “megafauna” have received attention. Megafauna are exemplified by large skates and rays that excavate large pits during foraging and large crustaceans such as lobsters, crabs and mantis shrimp that bury or burrow into the substrate. This topic was addressed for the Palos Verdes Shelf by Morris (1994), who concluded that the most likely significant megafaunal bioturbator on the shelf was the bat ray (*Myliobatis californica*). Although bat rays probably cause large-scale sediment disturbance, their pits are generally no deeper than 30 cm. Other potentially important megafauna included cuskeels and eelpouts, which are locally very abundant and spend significant amounts of time buried tail-first in the bottom.

Some degree of concern remains, however, with respect to "deep" bioturbators, for which few quantitative data exist. Previous studies of benthos in the region, including those sponsored by the Los Angeles County Sanitation Districts, were limited in terms of penetration capabilities of their sampling devices. Grabs generally sample to a depth of 10 to 15 cm, and box corers to a depth of 40 cm (only in unconsolidated sediments). Consequently, data on organisms potentially present at depths greater than 15 to 20 cm are unavailable.

[1] Personal Communication, 14 April 1997, Janet Stull, Senior Environmental Scientist, LASCD.

[2] Reference Memorandum, 28 February 1997, Mary Bergen, Benthic Ecologist, SCCWRP.

Of particular interest are thalassinid shrimps, a widely distributed taxonomic group that is known to include species capable of penetrating thick layers of surficial sediments and mixing large quantities of sediment. In other coastal environments, members of this taxonomic group have been shown to construct extensive burrow galleries to depths of at least 30 to 50 cm. Their densities on the Palos Verdes Shelf are unknown, although Wheatcroft and Martin (1994) reported that mud shrimp were present in box core samples collected at 5 of 8 stations. The species were not identified by Wheatcroft and Martin, however, Janet Stull identified these specimens as *Neotrypaea californiensis* and *Calocarides spinulicaudus*. These species belong to the thalassinid shrimp families Callianassidae and Axiidae respectively. Elsewhere, Axiids have been reported to burrow up to depths of 2 m (Pemberton, Risk, and Buckley 1976).

Although an extensive treatment of bioturbation by thalassinid shrimps exists in the scientific literature, studies largely are restricted to shallow water forms (e.g., Griffis and Chavez 1988, Ogden Environmental and Energy Services 1994). Without specific knowledge of species present on the Palos Verdes Shelf in terms of substrate affinities (e.g., preference for sandy versus silty sediments) and life history characteristics (e.g., deposit versus suspension feeders as that relates to capability to process organic carbon at depth), conclusions regarding the importance of deep bioturbation in the Palos Verdes Shelf region remain subjective.

Wheatcroft and Martin (1994) recommended that biodiffusivities in the 23 to 50 cm^2/year range be used to describe bioturbation effects in the upper 10 cm of the Palos Verdes Shelf sediment column. For deeper sediments they suggested that an assumption of exponentially decreasing biodiffusivity could be used (note that these recommendations were intended for modeling investigations of bioturbation processes). Stull et al. (1996) also reported that estimated biodiffusion coefficients decline rapidly with depth. It should be noted, however, that both Wheatcroft and Martin (1994) and Stull et al. (1996) identify the potentially important distinction between mixing by diffusive processes and by advective processes. The latter is attributed to "nonlocal" mixers, usually larger organisms that individually disturb sediments. Nonlocal mixers are represented by a number of organisms present on the Palos Verdes Shelf (a list is provided in Stull et al. 1996).

In considering bioturbation as a factor in design of dredged material caps for the Mud Dump site in coastal New York waters, a situation analogous in many respects to the Palos Verdes Shelf, Rhoads and Carey (1996) suggested that a cap thickness of 50 cm would provide conservative isolation of underlying contaminated sediments. This thickness would be equivalent to fives times the "universal mean bioturbation depth" of 9.8 $\pm$ 4.5 cm reported by Boudreau (1994).

Dredged material capping projects, however, are designed using a different overall approach and considering different spatial scales. Dredged material capping projects often involve placement of contaminated material at noncontaminated open water sites, and cap designs have tended to be very conservative with selection of bioturbation cap thickness components often based on isolation of the deepest burrowing organisms anticipated at the site. Further, dredged material capping projects involve smaller volumes and surface areas than the PV shelf project, and the designs for such projects are aimed at capping all the contaminated material of concern. For the PV shelf, the area of concern is very large, and an incremental capping approach will not isolate all the contaminated material of concern.

Based on these considerations, a cap thickness component for bioturbation of 30 cm should accommodate most concerns related to bioturbation effects on cap integrity for areas selected for isolation by the cap. A portion of the bioturbation depth should include a surficial layer in which the sediment can be assumed totally mixed and an additional depth of potential sediment biodiffusion for purposes of evaluations of the effectiveness of various cap thicknesses in reducing long term flux of contaminants. However, it should be noted that potential for recolonization by deep bioturbators and their effects on the cap are unknown. Note that Stull[1] speculated that significant bioturbation could occur to depths of 50 cm. The monitoring program for the project should therefore include components to assess the potential presence and behavior of deeper bioturbators and any effects on cap integrity (Chapter 5).

Consolidation Evaluation

Fine-grained granular capping materials may undergo consolidation due to self-weight. Underlying contaminated sediment may also undergo consolidation due to the added weight of capping material. The cap design should therefore consider consolidation from the standpoint of cap material thickness and interpretation of monitoring data. Since capping materials under consideration are predominantly sandy, no cap thickness component to offset cap consolidation over the long term is considered necessary.

A consolidation analysis of the underlying contaminated sediment is necessary for purposes of the contaminant flux analysis described below. Computation of the volume of pore water expelled is needed to estimate the thickness of cap affected by advection and that required to retain this volume.

The thickness of the EA sediment layer varies from a few centimeters to a maximum of about 60 cm. The maximum thickness is comparable to the upper

[1] Reference Memorandum, 14 April 1997, Jan Stull, Senior Environmental Scientist, LASCD

range of capping layer thicknesses contemplated. Further, the compressibility of the EA sediments varies from low to moderate as compared to fine-grained dredged sediments (Appendix C). Therefore the anticipated magnitude of consolidation was not expected to be large in comparison with the layer thickness.

The USGS had previously conducted consolidation tests on the EA sediments (Lee and McArthur in preparation), and data from these tests were used for this consolidation analysis. Because of the relatively small thickness of the layers, a straight forward and conservative estimate of the magnitude of consolidation using standard approaches was deemed appropriate.

Consolidation values were calculated for each USGS station for a range of applied capping thicknesses (up to 90 cm). The results for the station with the largest EA sediment thickness are summarized in Figure 10. Detailed calculations are presented in Appendix C. A map showing a spatial distribution of the magnitude of consolidation over the entire EA footprint for a 45 cm cap is shown in Figure 11. The spatial trends for other applied cap thicknesses would be similar.

The calculated changes in thickness indicate that the EA layer will be compressed on the order of 10 percent of its thickness due to placement of the cap thicknesses under consideration for the stations with the largest compressible layer thickness. For example, the maximum consolidation due to a 45 cm cap at any station was approximately 9 cm (about 3 in). Consolidation for other applied cap thicknesses would be proportional. The cap thickness occupied by the expelled water was approximately 18 cm (about 7 in), accounting for the fact that only void spaces in the cap would be occupied by the expelled water. Therefore, the water expelled by consolidation will easily remain within the cap thickness as placed.

Operational Considerations

Operational capabilities of equipment and constraints related to site conditions must be considered in cap design. Such considerations relate mainly to the ability of equipment to place a given design cap layer thickness considering site conditions such as wave climate or water depth and the ability to monitor that placement with acceptable precision.

For the PV shelf site, the site conditions of interest from the operational standpoint include the water depth, the large area to be capped, and the likely use of discharges of material from hoppers for placement (Chapter 4). Under these conditions, the cap thickness may vary locally, although the method of placement may result in only gradual variation in the cap thickness. Also, the cap material may potentially resuspend and mix with some of the EA sediment during placement. A potential variation of 5 to 10 cm is considered a conservative estimate for operational tolerance, allowing for some variation of the as-placed

cap thickness and some mixing with the EA sediment. Because of the large areas to be capped, the operational tolerance was not considered as a required component of the design cap thickness. Rather, this operational tolerance was considered in the context of evaluations of the isolation cap thickness requirements as described below and in Appendix D.

An operational tolerance in cap thickness was not considered appropriate for the thin cap design because the intent of the thin cap is to provide a proportional reduction in exposures, not isolation. Any variation in cap thickness under the thin cap scenario would result in some capped areas with higher proportional reductions in exposure and some areas with less.

Chemical Isolation Evaluation

The purposes of the chemical isolation evaluation are to define the needed cap thickness component for the isolation cap and to compare the isolation ability of the thin cap and the isolation cap with the no capping condition. This evaluation included laboratory testing, analytical evaluations, and cap effectiveness modeling using the WES RECOVERY model.

Chemical flux processes

Properly placed capping material acts as a filter layer against any migration of contaminated sediment particulates. With the exception of bioturbation mixing in thin caps, there is essentially no driving force that would cause any long term migration of sediment particles upward into a cap layer. Most contaminants of concern also tend to remain tightly bound to sediment particles. However, the potential movement of contaminants by advection (movement of porewater) upward into the cap or by molecular diffusion over extremely long time periods is possible.

Advection refers to the movement of porewater. For this evaluation, advection due to consolidation of the underlying contaminated sediment following placement of the cap was considered. Movement of porewater due to consolidation would be a finite, short-term phenomenon, in that the consolidation process slows as time progresses and the magnitude of consolidation is a function of the loading placed on the compressible layer. The weight of the cap will "squeeze" the sediments, and, as the porewater from the sediments moves upward, it displaces pore water in the cap. The result is that contaminants can move upward into the cap in a short period of time. However, DDT and PCB and their degradation products are poorly soluble, associated with organic matter, and tightly sorbed to the clay fraction. Some sorption is irreversible, and, as such, pore-water concentrations will be low.

Diffusion is a molecular process in which chemical movement occurs from material with higher chemical concentration to material with lower concentration. Diffusion results in extremely slow but steady movement of contaminants. The effect of long-term diffusion on the design cap thickness is normally negligible because long-term diffusion of contaminants through a cap is an extremely slow process and contaminants are likely to adsorb to the clean cap material particles.

Field and laboratory experience has shown that a properly designed and implemented cap will produce an effective chemical barrier (Thibodeaux, Vakaraj, and Reible 1994). Properly designed caps act as both a filter and buffer during advection and diffusion. As pore waters move up into the relatively uncontaminated cap, the cap sediments can be expected to scavenge contaminants so that any pore water that traveled upward would theoretically carry a relatively small contaminant load. As previously described, the cap thicknesses under consideration would contain the entire volume of pore water leaving the contaminated deposit during consolidation within the lower portion of the cap.

Approach for flux evaluation

The effectiveness evaluation was based on a conservative analysis using straightforward and well-accepted principles. Laboratory test results for consolidation and cap effectiveness were used to define parameters necessary for the evaluations, and a combination of analytical and numerical models was used to calculate the flux for the desired range of conditions. Both advective and diffusive processes were considered.

Two types of flux evaluations were performed. First, a comparative analysis was carried out for a single contaminant profile (as defined by USGS station 556), considered representative of the more contaminated “hot spot” on the shelf. This comparative evaluation included a prediction of contaminant flux for a range of cap thicknesses and possible conditions related to the flux. The results of the comparative evaluation could be considered a “sensitivity analysis”. The results were then used in determining appropriate conditions for evaluation of flux for all sediment contaminant profiles as defined by the USGS box core data. The results of these “production” model runs were used to define the exposures of contaminants over the wider areas on the shelf considered for capping.

Cap effectiveness testing

Laboratory tests were conducted to develop sediment specific values for the EA contaminated sediments and for representative dredged material caps. Results of these tests yield sediment-specific and capping-material-specific values of partitioning coefficients used for the evaluation of advective flux due to consolidation. Samples of PV shelf material were obtained from USGS archived

cores, and samples of the Queen's Gate sediment were obtained through CESPL. Partition coefficients were measured using diffusion tubes (DiToro, Jeris, and Clarcia 1985). Details on this test are presented in Appendix D.

Advective flux evaluation

Advective flux is due to movement of pore water upward into the cap. Equilibrium partitioning was the theoretical basis for estimating contaminant concentrations in pore water advected by consolidation (Hill, Myers, and Brannon 1988). The magnitude of consolidation and the movement of pore water due to consolidation were calculated as described above, and these values were used to adjust the sediment contaminant concentration profiles to account for movement of contaminants due to advective flux prior to evaluation of long-term diffusive flux using the RECOVERY model. It should be noted that all pore-water movement due to consolidation would be retained in the lower portion of the cap layer. Details of this evaluation are presented in Appendix D.

Diffusive flux modeling with RECOVERY

Any detailed assessment of diffusive flux must be based on modeling since the processes involved are potentially very long term (potentially hundreds to thousands of years). Diffusive flux of contaminants was calculated using a refined version of the WES RECOVERY model (Boyer et al. 1994). The model can estimate long-term diffusive fluxes in a system composed of a completely mixed water column, a completely mixed sediment surface layer, and a variable underlying sediment contaminant profile. Details of the modeling effort are presented in Appendix D.

The model considers the thickness of sediment layers, physical properties of the sediments, concentrations of contaminants in the sediments, distribution coefficients, and other parameters. The results generated by the model include changes in sediment concentrations, flux rates, and pore-water concentrations. Such results can be interpreted in terms of a mass flux of contaminants as a function of time and serve as a basis of selecting optimum cap thicknesses.

The thickness of the mixed surface layer and the diffusion coefficients are parameters which influence the results. Diffusion coefficients were based on literature values. The effect of biodiffusion was simulated with the model by adjusting the molecular diffusion coefficient for the layer thickness affected by biodiffusion such that the rate of contaminant movement was analogous to the sediment biodiffusion rate measured by NOAA studies (Drake, Sherwood, and Wiberg 1994).

The bioturbation analysis indicated that most of the benthic organisms inhabiting the cap will likely be "shallow" bioturbators, with sediment mixing

largely occurring within the uppermost 15 cm of the sediment column. An appropriate thickness for the thin cap, necessary to isolate the contaminants from most biological activity, would therefore be 15 cm. The isolation cap, which should provide complete physical isolation of the contaminated sediment from benthic organisms as well as chemical isolation, would require a material thickness greater than 30 cm, the depth of intensive bioturbation plus biodiffusion.

The comparative runs established trends for changes in DDT sediment contaminant concentrations, pore-water contaminant concentrations, and flux to overlying water (trends for PCB would be similar). Simulations were made to evaluate the effect of variations in depths of biodiffusion, biodiffusion rates, thickness of the isolation cap component, sediment deposition rate, and DDT degradation rate.

The comparative runs indicated that a 15-cm mixed layer with biodiffusion to a depth of 30 cm closely simulates the actual contaminant profiles and measured biodiffusion behavior. These mixed layer and biodiffusion thicknesses were used for the production runs. Comparative runs were also made considering degradation of the contaminants in pore water. The results of this comparison yielded relatively small differences in the exposures over relevant time scales; therefore, no degradation of contaminant was assumed for the production runs. Conditions with a continuous but slow buildup of new sediment did show a dramatic effect on the results; however, the assumption of a long-term sedimentation rate is considered nonconservative and a near zero net sedimentation rate of 0.04 cm/yr was used for the production runs.

Thickness for isolation was also evaluated as a part of the comparative runs, and a range of cap thicknesses in excess of the 30-cm bioturbation thickness were modeled. These results indicated that a total cap thickness of 35 cm would provide approximately a two order of magnitude reduction in DDT concentration in the mixed layer as compared with a 30-cm cap thickness, while a 40- or 45-cm thickness would provide a three order of magnitude reduction. Consideration of a 10-cm operational component for variation in the cap thickness during placement resulted in a final design cap thickness for the isolation cap of 45 cm, and this thickness was used for the production runs.

For existing conditions (no cap), modeling results showed the flux and mixed layer sediment and water concentrations are at their peak initially, decreasing slowly with time. For all no cap conditions, no substantial decreases in concentrations in the mixed layer were evident for extremely long time periods.

Placement of a 15-cm thin cap over the contaminated sediments will not provide a complete isolation from surficial mixing/biodiffusion, and contaminants will be moved into the clean cap material by biodiffusion at a faster rate than by molecular diffusion. For the 15-cm cap, initial concentrations and flux begin to increase immediately and reach a peak value in approximately 1,000 years. The

peak fluxes and concentrations are roughly 9 percent of the no cap condition. Therefore, the thin cap provides significant isolation from the standpoint of chemical contaminant migration. However, the thin cap does not provide effective isolation of the contaminated sediment from benthic organisms.

Results for a 45-cm isolation cap showed essentially complete isolation for over a hundred years followed by very low flux for extremely long time periods. Changes in sediment profiles generally indicate that the contaminant mass migrates downward over extremely long time periods. Based on the results of the 45-cm runs, long term isolation was achieved, and a 45-cm total thickness was found be adequate for an isolation cap design.

Production runs were made for each sediment profile as defined by the USGS data for the no cap, 15-cm thin cap, and 45-cm isolation cap. These were made for both DDT and PCB. A sediment mixed layer thickness of 15 cm, a biodiffusion layer to 30 cm, and no degradation were used for all production runs. RECOVERY was used to calculate the sediment contaminant concentrations in the surficial mixed layer, sediment pore water contaminant concentrations in the surficial mixed layer, and contaminant flux to the overlying water for each sediment profile as defined by the USGS data. Results for these runs are summarized in Appendix D.

Recommended Cap Designs

An evaluation of bioturbation in the context of cap design indicated that most of the benthic organisms inhabiting the proposed project area are "shallow" bioturbators, with sediment mixing largely occurring within the uppermost 15 to 20 cm of the sediment column. Bioturbation can occur to deeper sediment depths at much lower rates, and a cap thickness component for bioturbation of 30 cm should accommodate most concerns related to bioturbation and biodiffusion effects. An erosion evaluation indicated that no cap thickness component would be required for erosion for water depths exceeding about 40 m. Rather than adding a cap thickness component for erosion, the area designated for capping should be limited to depths greater than 40 m.

The evaluation of cap effectiveness in controlling contaminant flux indicated that significant flux reduction could be achieved by a 15-cm thin cap. Based on these results, a 15-cm thickness is adequate for a thin cap design (Figure 12). The thin cap achieves the function of physical isolation of the shallow burrowing benthic organisms, but does not isolate the contaminated sediment from all benthic biological activity.

A 45-cm cap thickness is adequate for an isolation cap (Figure 12), since it exceeds the limits of significant bioturbation and provides practically complete chemical isolation over the long term. An operational tolerance of 10 cm was

considered in the evaluations of effectiveness for the isolation cap, but was not considered a necessary additional cap thickness component. The target cap thickness for placement of the isolation cap would be 45 cm, but areas later determined by monitoring to have thicknesses in excess of 35 cm would not require additional cap material.

Capping Options

With two large capping area prisms defined and two possible cap design thicknesses, a 15-cm thin cap and a 45-cm isolation cap, there are a number of possible combinations or options for capping. Prism B contains sediments with much lower contaminant concentrations than prism A. Based on the results of the capping effectiveness evaluation, placement of a given cap thickness (15 or 45 cm) on prism A would therefore have a much more pronounced reduction in all exposures than the same cap placed on prism B. Based on this fact, three representative capping options were defined:

Capping Option 1 - Placement of a 45 cm isolation cap over prisms A and B

Capping Option 2 - Placement of a 15 cm thin cap over prisms A and B

Capping Option 3 - Placement of a 15 cm thin cap only over prism A

Methods to construct these caps are described in Chapter 4. Additional capping area and thickness options could also be considered.

Reductions in Potential Exposures

The placement of a cap will result in a reduction in potential exposures of contaminants to organisms. Populations and community structures of organisms may be different for the shelf area than for the deeper slope and basin areas. Therefore, reductions in potential exposures were computed separately for the shelf and slope.

For this evaluation, exposures of interest were defined as sediment concentrations in the mixed layer, pore water concentrations in the mixed layer, and flux to the water column. The area of interest was defined as the shelf area within the EA footprint but with a water depth shallower than 70 m. First, simple averages of the potential exposures were computed for both DDT and PCB. These parameters are time dependent, and values at 100 years following cap placement were used to compute the averages. Separate averages were computed for stations inside and outside prisms A and B and above or below the shelf break at the 70-m depth contour. In this way, the relative magnitude in the reductions in

exposure for the portion of the footprint on the shelf were determined for capping options 1, 2, and 3.

Table 1 illustrates the relative reductions in exposure based on the station averaging. It can be seen that option 1 (45-cm isolation cap over prisms A and B) results in a reduction in potential exposures over the total shelf area on the order of 85 percent, option 2 (15-cm thin cap over prism A and B) results in reductions on the order of 75 percent, and option 3 (15-cm thin cap over prism A) results in reductions on the order of 65 percent. For these measures of exposure, capping additional surface area results in more reduction of exposure than additional cap thickness.

To further illustrate the spatial variability of the results over the shelf, the data for DDT flux at 100 years for the no cap condition and following 45-cm cap placement were entered into the GIS, and contours of the flux were plotted as shown in Figures 13 and 14. The reduction in the flux exposure based on the GIS values are comparable with those computed by the station averages (76 percent reduction versus 88 percent reduction). The differences in results for station averages versus GIS-computed averages for DDT sediment and porewater concentrations and for PCB would be similar.

Since the cap can only be placed between the 40- and 70-m depth contours, the fluxes over the entire EA footprint cannot be completely reduced by capping prisms A and B. However, approximately 75 percent of the total mass of contamination lies on the shelf and most of this mass can be capped. The sediment concentrations, pore water concentrations, and flux to the water column can be reduced over the shelf area on the order of 65 percent to 85 percent, depending on the capping option.

4 Cap Placement and Operations Plan

General Considerations

The major consideration in selection of equipment and placement methods for the cap is the need for controlled, accurate placement of capping material. In general, the cap material should be placed so that it accumulates in an even layer covering the contaminated area. The use of equipment or placement rates which might result in excessive displacement of the capping material, excessive mixing of capping and contaminated material, or excessive resuspension of the contaminated material should be avoided.

For a project such as the PV shelf, a detailed operations plan would be required prior to preparation of plans and specifications for a given phase of the work. The plan should include equipment selection, placement methods for that equipment, cap design (thickness), defined areas to be capped, sequence of capping, and calculations of volumes of cap material required. This chapter defines several capping options involving a range of cap thicknesses and areas and serves as a preliminary operations plan for those options. If an option for in situ capping is selected for implementation, a more specific and detailed operations plan would be required.

Equipment Selection

The NOAA study (Palermo 1994) concluded that a number of different equipment types and placement techniques are possible for in situ capping on the shelf, to include spreading by barges and placement by hopper dredges. Dredged material released as discrete loads at the water surface from hoppers or barges tends to descend rapidly to the bottom as a dense jet with minimal short-term losses to the overlying water column (Bokuniewicz et al. 1978, Truitt 1986). The surface release of mechanically dredged material from barges results in a faster descent, tighter mound, and less water column dispersion as compared to surface

discharge of hydraulically dredged material, as from a hopper dredge. Typically, surface release of hydraulically dredged material from a hopper dredge takes longer than that from a barge, the resulting mound or deposit is looser, and there is more water column dispersion.

Hopper dredges are recommended as the equipment of choice for capping on the PV shelf for the following reasons:

a. Hopper dredges are the most likely type of equipment used to deepen and maintain the navigation channels in LA/LB harbor, a major potential source for capping material in the long term.

b. Hopper dredges remove material from channels by hydraulic means, resulting in a breakdown of any hardpacked material and addition of water as material is stored in the hopper for transport. Material from hopper dredges is therefore more easily dispersed in the water column, and would therefore settle to the seafloor with less energy and less potential for resuspension of the contaminated sediment.

Conversations with the USACE Los Angeles District (CESPL) confirmed that navigation dredging in the harbors is most likely to be done using hopper dredges. This will thoroughly mix the sand, silt, and clay sediments. Even with dredging to overflow (which CESPL indicated they will allow, though with the fine grained material there may not be much load gained by overflow), the material in the hopper should be fairly loose and thus should quickly exit the dredge, even with a narrow cracked-hull opening. This information is based on conversations with Mr. Anthony Risko (CESPL Coastal Planning, formerly in Operations Division), who both modeled and witnessed a capping operation of sediments placed in a borrow pit in Los Angeles/ Long Beach Harbor, and Mr. William Pagendarm of North Atlantic Trailing Company (NATCO), the firm with the largest hopper dredge fleet in the United States.

The design channel depth for the Queen’s Gate project is 23 m (76 ft) (mllw) plus 1.3 m (4 ft) of allowable overdepth, for a total dredging depth of 24 m (80 ft). The only two contractor-owned hopper dredges based on the west coast, Manson’s Newport and Westport, can only dredge to about 17 m (55 ft) and thus are most likely not suitable for this project without significant modification. NATCO dredges work regularly on the west coast, their Island class dredges are capable of dredging to 21 m (70 ft) and could be modified to dredge to 24 m (80 ft) without much difficulty. Therefore the Manhattan Island class dredges were selected for modeling of disposal operations. Mr. William Pagendarm of NATCO was contacted for dredge characteristics and advice on disposal volumes and durations for the Queen’s Gate sediments.

The Manhattan Island class dredges disposing of the Queen's Gate sediments would likely have a hopper load of 1,380 m^3 (1,800 yd^3), a loaded draft of 5.8 m (19.4 ft), and a light draft of 3.0 m (10.0 ft) and would require an estimated 2 min for 90 percent of the material to exit the dredge, with all material exiting in 5 min. A photo of the Manhattan Island hopper dredge is shown in Figure 15.

The load limit capacity for a hopper dredge is less than total volumetric capacity when dredging dense sandy sediment. The 1,380-m^3 (1,800-yd^3) volume is considered an efficient load for a fine sandy material such as the Queen's Gate material, considering bulking and loss of fines due to resuspension on the channel bottom by the dragarms and overflow during hopper loading.[1] The efficient load for the sand borrow material would likely be higher.

It is informative to place the relative size of the dredge in perspective with the water depths at the site and the scale of the area to be capped. Figure 16 illustrates a cross section perpendicular to the shore at Whites Point. This section is drawn to true scale and shows the relative length of a Manhatten class hopper dredge as compared with the width of the capping area between the 40-m and 70-m depth contours and the variation in water depth for the shelf. It can easily be seen that the capping "target" is quite large compared to the dredge and that the capping material can be placed with sufficient accuracy to accumulate over the target.

Placement Methods

Hopper dredges normally release the load of material from the bottom of the dredge through a series of door like mechanisms or through a split-hull mechanism. The release is normally done at a specified point or at a moored buoy. This "point dumping" approach is referred to in this report as the conventional hopper dredge placement method. Hopper dredges can also be used to intentionally spread material for purposes of capping. During the summer and fall of 1993, the Port Newark/Elizabeth capping project in New York Bight used hopper dredges to spread a sand cap over 440,000 m^3 (580,000 yd^3) of contaminated sediments at a water depth of approximately 20 m. To facilitate spreading the cap in a thin layer (6 in) to quickly isolate the contaminants and to lower the potential for resuspension of the contaminated material, conventional point dumping was not done. Instead, a split hull dredge cracked the hull open 1 ft and released its load over a 20 to 30-min period while sailing at 1-2 knots. Also, as an alternative means of placing the cap, another dredge used pump-out over the side of the vessel through twin vertical pipes with end plates to force the slurry into the direction the vessel was traveling. As with the cracked hull method described above, injecting the slurry into the direction of travel of the vessel

[1] Personal Communication, William Pagendarm, Vice President, NATCO.

increased turbulence, reducing the downward velocity of the slurry particles and thus the potential for resuspension of the contaminated sediments. Computer models were used to predict the width of coverage from a single pass and the maximum thickness produced (Randall, Clausner, and Johnson 1994). Methods such as slow release underway or pump-out are referred to in this study as spreading placement methods. Both the conventional and spreading placement methods were evaluated for this study.

Placement Cells

The total areas of prisms A and B are about 4.9 and 2.7 km^2, respectively. Since the area is so large, it was broken into placement cells of 300 by 600 m (Figure 17). This size was convenient for modeling simulations as described below. A series of such cap placement areas is superimposed on the boundaries of prisms A and B in Figure 18. The use of cells also has advantages from both the operational and monitoring standpoints. The location of the cells in Figure 18 was established to provide a complete coverage of the prisms. A total of 37 cells are required for coverage of prism A, while an additional 19 cells are required for coverage of prism B (note that some of the cells necessarily overlap the boundaries of the prisms).

Cap Placement Modeling

Cap placement modeling was conducted to simulate cap placement operations and to determine placement methods necessary to build a cap for the conditions on the shelf. The model results were used to develop a recommended operations plan which included placement spacings and rates of placement. If capping options are selected for the shelf, the placement methods as defined by the model simulations should be field verified and adjusted as appropriate, based on monitoring conducted on the initial cap placement efforts. Appendix E describes this modeling effort in detail.

The USACE Multiple Disposal FATE (MDFATE) model was used for this evaluation. MDFATE incorporates features of the Short Term FATE of dredged material (STFATE) model (Johnson and Fong 1993), which simulates the placement of a single load of dredged material, and the Long Term FATE of dredged material (LTFATE) model (Scheffner et al. 1995), which predicts the long-term stability (days to years) of dredged material mounds.

The material characteristics and site hydrodynamics as described in Chapters 2 and 3 were used in the modeling effort. Modeling was conducted for two placement approaches using a Manhattan Island class hopper dredge:

a. conventional placement methods where discrete surface release from the hopper at a specified point is utilized and

b. spreading placement method where the material is slowly released through the slightly cracked split hull of a hopper dredge and falls to the bottom at a determined particle settling velocity.

Results for the modeling of spreading placement for Queen's Gate material indicated that the slow particle settling velocity combined with the tidal and residual currents resulted in wide distribution of the suspended fraction of the sediments well beyond the placement area. Based on these results, extremely large volumes of material would be required to build caps by spreading methods at this site with thicknesses greater than 15 cm using mixtures of fine sand and silt/clay. However, the spreading method was effective for a 0.2-mm sand and did create suitable cap thicknesses.

A system of placement lines or lanes and spacings for discrete releases of material from the hopper dredge was devised for the conventional placement evaluation. The lane spacing and number of placements per lane were varied to create an in situ cap with the range of desired thicknesses, 15 to 45 cm. Results indicated that the target cap thicknesses of 15 to 45 cm can be readily achieved by conventional placement techniques. In general, various combinations of line and placement spacings in sequential operations or lifts could be used to achieve a target cap thickness.

A cap thickness of 15 cm, using Queen's Gate material, can be achieved using a 60 m (200 ft) placement spacing and a 60-m (200-ft) line spacing. A target cap thickness of 45 cm can be achieved using three passes with the same spacing as for the 15 cm cap or two lifts with a 45-m (150-ft) placement spacing with 60-m (200-ft) line spacing.

For the spreading method of placement for the borrow area material, a line spacing of 60 m (200 ft) would be appropriate with spreading accomplished over the length of the lines corresponding to the vessel speed and discharge time period. The 200-ft line spacing would result in a 15-cm cap thickness for each pass, therefore construction of a 45 cm cap would require 3 passes over each cell using the spreading method.

As described in Appendix E, the model simulations are slightly conservative in that the modeled final cap thickness is slightly greater than the 15- and 45-cm targets. It should also be noted that these volumes include the portion of the material as released from the dredge that does not contribute to the cap thickness over the overall target area. A schematic of the placement points and lines within a typical cap placement cell for this placement option is shown in Figure 17.

The placement point and line spacings above result in the desired cap thicknesses of 15 or 45 cm over prisms A and B. Additional capping of areas outside prisms A and B would also occur with lesser thicknesses due to the settling of material to the bottom outside the prisms. This additional capping would occur primarily in areas to the northwest of the prisms on the shelf as cap material is carried in the “downstream” direction by alongshelf currents. Although the areas northwest of prisms A and B are areas with lower levels of contamination, some additional benefits due to reduced contaminant exposure would result.

Monitoring (Chapter 5) is necessary to validate these predictions. If a specific project is selected as a cap material source, the model simulations should be updated for a specific dredge and for sediment characteristics. After a prediction of cap thickness has been made, a number of placements should be well monitored to include the dredge load characteristics (volume, percent solids, and grain size) and placement data (exit time, location, speed and heading) in addition to the cap geometry. This information can then be used to fine tune the model predictions.

Sediment Resuspension and Cap Plume Dispersion

If Queen’s Gate material is used (either directly during the deepening project or by later rehandling from the West Anchorage Disposal Site), the finer fractions of the sediment will become suspended in the water column during placement. This is also true for placement for the borrow area material, although to a lesser degree. The turbidity and suspended solids plume associated with cap placement must therefore be considered.

The STFATE model was used to evaluate plume total suspended solids (TSS) concentrations as a function of time. Results of the simulations indicated that TSS concentrations in the plume would decrease to tens of milligrams per liter at near bottom and to less than 1 mg/l at middepth in the water column after a few hours. Based on these results, short term impacts to water quality in the immediate vicinity of the capping operations could be expected, but the effects would be temporary.

The STFATE model results were also used in conjunction with a simple energy-based model called SURGE to evaluate the potential for resuspension of the in situ EA sediment during cap placement. These models were used to compute the distance and speed of the spread of material along the bottom for both the hopper conventional and hopper spreading method of placement. The velocities were then compared with critical shear stresses for resuspension as determined by earlier NOAA resuspension studies. Details of this evaluation are presented in Appendix E. Results indicated that the potential for resuspension will

exist for only short periods of time and the area of influence of the potential disturbance is very small compared with the total area covered by any single hopper discharge. A comparison of the conventional placement method with the spreading method indicated that potential disturbance can be reduced by over an order of magnitude by using the spreading mode of cap material placement. The spreading mode of placement could therefore be used as a management approach to limit potential resuspension, at least for the initial layers of cap material placed over a larger area.

Using this management approach, the cap placement operation would be accomplished using two placement methods if the Queen's Gate sediment was used as a cap material source. A thin layer of cap material would be initially placed by spreading methods. The placement of this layer has low potential for resuspension, and, once in place, the layer would reduce the potential for EA sediment resuspension by subsequent cap material placement using the conventional placement method. This initial layer would be most efficiently placed using the coarser 0.2-mm material from the borrow areas outside the harbor breakwaters. A portion of the total cap material placed in this manner would be appropriate for this purpose.

Cap Placement Sequence

Because of the large area to be capped, it is more advantageous to place at least the thin design cap thickness over a given portion of the area as material becomes available for capping as opposed to placement of a very thin layer which may become quickly bioturbated. Therefore, if the 15-cm cap option is selected for a given area, and the design thickness is not achieved in a single pass using spreading methods or series of releases using conventional placement methods, the entire 15-cm thickness should be placed in each cap placement cell using multiple passes before operations are shifted to another cell. This approach is preferred because the initial 15-cm thickness would provide isolation before significant recolonization and subsequent bioturbation occurs.

If the 45-cm cap option is selected for a given area or prism, it is advantageous to place the 15-cm thin cap thickness over the entire area first. This thickness cuts the surficial mixing mechanism due to bioturbation and provides an immediate reduction in exposures. The remaining 30-cm cap thickness can then be placed as two separate lifts in sequence over the area to be capped.

The preferred sequence of placement of material in a series of cap placement cells 300 by 600 m is indicated by the number sequence for the cells shown in Figure 18. This sequence begins with the southeasternmost cell and progresses in order to the northwest. Such a sequence would result in the lowest potential for recontamination of the cap surface from adjacent areas since the prevailing currents are from southeast to northwest.

Based on these considerations, the following specific cap placement sequences (referenced to Figure 18) are recommended for each capping option:

a. Capping option 1 (45-cm prism A+B)
Place lift one of 15 cm sequentially in cells 1 through 56.
Place lift two of 15 cm sequentially in cells 1 through 56.
Place lift three of 15 cm sequentially in cells 1 through 56.

b. Capping option 2 (15-cm prism A+B)
Place one 15 cm lift sequentially in cells 1 through 56.

c. Capping option 3 (15-cm prism A)
Place one 15 cm lift sequentially in cells 1 through 37.

Capping at the Whites Point Outfalls

The capping sequence described does not include any special provisions for capping the area surrounding the outfalls. If the cap thicknesses are limited to 15 or 45 cm (about 6 to 18 in), actual clogging of ports on the outfalls is not likely to be a problem. However, cap material would accumulate over the stone cover. Reballasting with rock piled above the level of the ports could increase the possibility of port plugging by cap material. Cap material over the rock ballasting cover may also impair the ability to monitor the condition of the ballast.[1]

Several approaches could be considered to manage cap placement at the outfalls. First, cap thickness could be reduced in the immediate vicinity of the outfalls. This could be accomplished by eliminating the placement locations immediately adjacent to the outfall pipe centerline, allowing the cap material thickness in the vicinity of the pipes to be built up from only near-adjacent disposal points. Since the diameter of the pipes is small and the spacing of the disposal points is on the order of 100 m or so, the area for which the cap thickness would be reduced would only be on the order of a few percent of the total area of prism A. Other methods which could be considered for additional control or management of the placement over the outfall area include the use of alternate placement equipment and methods, such as smaller hopper equipment or spreading techniques for slower buildup of the cap, or the use of special downpipes or pumpout from hopper dragarms for submerged discharge during placement. Another approach is to provide for removal of cap material which may build up around the immediate vicinity of the outfall ports or over ballast immediately adjacent to the pipe. Small submarines have been used by LACSD for outfall inspection, and such a submersible equipped with a jetting or suction device could be considered for this management approach. Monitoring efforts during cap

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[1] Personal Communication, 22 July 1997, Bob Harvath, Technical Services Department, LACSD.

placement in the vicinity of the outfalls could be designed to allow for early detection of any potential problems. Special management provisions for the immediate vicinity of the outfalls should be considered in more detail depending on the capping option selected.

Navigation and Positioning

Experience gained in capping the Port Newark/Elizabeth project from New York Harbor mentioned earlier, along with other Corps experience, has shown that the actual capping operation should be straightforward. To achieve the placement accuracy desired, a series of controls would be required. Most critical is the use of a highly accurate horizontal positioning system on the dredge. A navigation/positioning system using Differential Global Positioning System (DGPS) is recommended. DGPS has a horizontal accuracy of about 2 m or better. DGPS positioning systems are now standard equipment on virtually all hopper dredges.

The navigation and positioning system must include a helmsman display that shows the position of the dredge relative to the programmed track line. This will allow the operator to position the dredge to within one vessel width (approximately 15 m) of the desired location. Prior to starting conventional placements for depths of 65 to 70 m and less, a series of transects (lanes) with the desired lane spacing and placement locations to be used would be preprogrammed into the navigation/positioning system computer. If the spreading placement mode is used for placement of cap material in water depths of 65 to 70 m or greater, the vessel track line will be programmed. Because it takes a minimum of 20 to 30 min for the vessel to place its load, considerations for turning at the end of the lane will need to be included. Most modern hopper dredges with bow thrusters require a turning area the diameter of their own length or less. Depending on the desired lane spacing, it may be appropriate for the dredge to proceed up one lane and then turn (placing material continuously), and return the second lane over. The exact procedure would have to be worked out with the vessel captain prior to the operation. A track plot, both electronic and hard copy, showing the placement locations, should be provided to supplement the disposal logs.

Required Cap Volumes

The volumes of capping material required will be a major factor in determining how quickly areas of the shelf could be capped at the design cap thicknesses. Table 2 indicates the areas, cap thicknesses, and required volumes of material to place the caps for capping options 1, 2, and 3. The volumes required to achieve the given cap thickness for each option are taken from the modeling results and calculations described in Appendix E. These total volumes were intentionally calculated as conservative estimates.

Required Time for Cap Construction

Required times for cap construction would be a function of the number of dredges brought to bear, the hopper capacities, the number of working days per year, the time required to fill, transport, and place the material taken from the various cap material sources, and other factors. Appropriate parameters to estimate the cap construction time were based on personal communication with Mr. Tony Risko, CESPL.

A typical hopper dredge fill time for hard-packed sandy material is approximately 2 hrs. With a hopper speed of about 7.5 knots underway during transport (one knot is about 1.15 statute miles per hour), the round trip time between the PV Shelf and Long Beach is about 2 hrs. An on-station time of 0.5 hrs would be sufficient to establish position for discrete placement points or establish line position for spreading points, and to release the material. Considering these factors, the estimated cycle time (the time from the beginning of a hopper filling to the beginning of the next hopper filling) is approximately 4.5 hrs.

The estimated construction season for work in the outer harbor area is approximately 300 days per year, considering weather conditions. Assuming 300 working days per year, and 24 hours of operations per day, approximately 1600 hopper loads per construction season could be placed with a single Manhattan class dredge. The total number of hopper loads required for construction ranges from less than 1,000 to over 5,000, depending on the capping option and cap material source. The estimated construction times using a single dredge range from approximately 0.6 to 3.3 construction seasons. All these parameters are summarized in Table 2.

The time for construction could be shortened by using multiple hopper dredges. In fact, to use the Queen's Gate material source within the approximate 18-month timeframe of availability would require a minimum of 2 hopper dredges.

Cap Maintenance

No erosion was predicted for a cap placed between the 40-and 70-m depths. Therefore no annual cap maintenance is anticipated.

Construction Cost Estimates

Cost estimates for placement of capping material on the PV shelf using a number of different options were prepared for this study by Mr. Tony Risko, CESPL. The preliminary estimates were calculated following discussions with local dredge contractors regarding expected costs to utilize various dredge and

disposal platforms to place the dredged material or borrow material at the project site. The equipment includes hopper dredges, clamshell dredges (disposal with tugs and scows), and hydraulic pipeline dredges. The primary assumptions used to compute the cost estimates and details on the preparation of the estimates are provided in Appendix G. This information was used to develop a range of total costs for cap placement for the various capping options. The cost estimates include mobilization/ demobilization where appropriate (Appendix G).

The source of the capping material is a major determining factor for cost. Therefore, a range of total costs for cap placement for each of the capping options 1 through 3 was prepared considering both the material sources and assuming the use of a hopper dredge. The low range costs assume that capping would take advantage of the Queen's Gate navigation project during the period of Queen's Gate dredging. The high-range costs assume that none of the Queen's Gate material would be available during the period of Queen's Gate dredging, and the borrow areas would be used as the cap material source.

As discussed in Chapter 3, the Queen's Gate navigation project could generate up to 6 million cubic yards (in-channel volume) of dredged sediments potentially suitable for capping material. This is less than the total required for Option 1, but the shortfall was assumed to be taken from overdredging the channel. If capping is implemented as a response action for the shelf during the timeframe of dredging Queen's Gate, use of these materials directly from the dredging process (without rehandling) could result in significant cost savings, because the dredging cost and a portion of the transport and placement cost could be considered as a navigation project cost and not counted as a capping cost. CESPL plans to place approximately 3,500,000 yd^3 (in-source volume) of the Queen's Gate Material in the anchorage area site (assuming it is not used for capping during the dredging process). The cost of using materials from the borrow area sources or West Anchorage Disposal Site source is higher, because the cost of dredging or rehandling the material and the full cost of transport and placement must be considered as a capping cost. Since the materials are of better quality in the sand borrow areas, rehandling Queen's Gate material from the anchorage site was not used in developing the cost estimates.

The estimates for use of dredged material directly from the Queen's Gate project considered the cost differential to transport the material to the PV shelf at Whites Point versus transporting the sediments to the ocean sites or the West Anchorage Disposal Site in the harbor. The differential for placement at LA-2 or LA-3 is negligible, but the differential for placement in-bay at the West Anchorage Site is $1.79 per in-hopper cubic yard (note that all unit costs presented in Appendix G are in terms of in-hopper or in-barge volumes). Since CESPL plans to place over half of the Queen's Gate material at the anchorage site, this differential was used for the Queen's Gate source.

Cost estimates were also prepared for obtaining cap material from borrow area sources outside the LA/LB harbor. The unit costs of using sand borrow would include dredging, transport and placement cost, ranging from $4.78 per cubic yard to $5.44 per in-hopper cubic yard, depending on the volumes dredged. The unit costs used in these estimates were a function of the volume dredged from the borrow source (Appendix G).

Table 3 summarizes the volumes from each source, unit costs, and total construction costs with contingencies for each capping option. Additional costs associated with monitoring efforts and administration of the project over time are not included in these estimates, but are discussed in Chapters 5 and 6.

5 Monitoring and Management

Monitoring Requirements

Monitoring is required to ensure that the cap is placed as intended and that the cap is performing the basic functions of physical isolation of the contaminated sediment from the benthic organisms and reduction of contaminant flux. Monitoring is required before, during, and following placement of the capping material to ensure that an effective cap has been constructed (this activity also may be defined as construction monitoring). Monitoring is also required to ensure that the cap as constructed is effective in isolating the contaminants and that long-term integrity of the cap is maintained (this activity also may be defined as long-term monitoring or cap performance monitoring). More intensive monitoring is usually necessary during and immediately after construction, followed by long-term monitoring at less frequent intervals.

Design of the Monitoring Plan

The design of the monitoring program/plan for the project as described here follows a logical sequence of steps (Fredette et al. 1990; Palermo, Fredette, and Randall 1992):

a. Designating site-specific monitoring objectives

b. Identifying phases, components, and elements of the monitoring plan

c. Predicting responses and developing testable hypotheses

d. Designating sampling design and methods (to include selection of equipment and techniques)

e. Designating management options

The monitoring program should also be multi-tiered (Palermo, Fredette, and Randall 1992; Fredette et al. 1986), with each tier having its own

unacceptable environmental thresholds, null hypotheses, sampling design, and management options should the thresholds be exceeded.

Capping on the PV Shelf would be done in an incremental fashion until the total selected area was capped. Several options with specific capping prisms and capping thicknesses have been defined. Since these prisms or areas are large (on the order of several square kilometers), capping placement cells 300 by 600 m have been defined for purposes of managing the placement of material in a priority order (Chapter 4). The capping placement cells also provide a more efficient means of managing the monitoring program and can be used as a reference to define specific sampling or monitoring stations. This is appropriate because the monitoring concerns (both construction and long-term monitoring) are similar over the larger area to be capped, regardless of the capping option selected. Therefore, the monitoring program described here would apply equally to placement anywhere within the overall area to be capped.

Monitoring objectives

Setting attainable and meaningful objectives is a necessary first step in the design of any monitoring program/plan. Appropriate monitoring objectives for the PV shelf project would include the following:

a. Define areal extent and thickness of the cap as initially placed
b. Determine that desired capping thickness is maintained
c. Determine extent of recolonization of biology and bioturbation potential
d. Determine cap effectiveness in isolating contaminated material from the benthic environment

Based on these objectives, the monitoring program should focus on cap thickness, cap benthic recolonization, and physical and chemical characteristics of the cap over time. These monitoring objectives focus on cap construction and performance, and should be considered separate from other monitoring required to evaluate the overall effectiveness of a capping remedy.

Monitoring equipment and techniques

A variety of equipment and techniques have been used to monitor subaqueous capping projects. These normally include bathymetry, subbottom acoustic profiling, sediment core sampling, biological sampling, and sediment profile camera (SPC) images. With the exception of bathymetry data collected from a surface vessel, these same techniques are applicable to the PV shelf project. As with cap placement, navigation and positioning equipment are needed to accurately locate sampling stations or survey tracks in the disposal site area. State-of-the-art positioning systems are recommended for all monitoring activities.

Monitoring phases, components and elements

The recommended monitoring plan to meet the above monitoring objectives is organized in phases and elements as summarized in Table 4. The plan is developed as two major phases: cap construction monitoring and long term cap performance monitoring. The focus of cap construction monitoring is to ensure that the cap is initially constructed as designed. The focus of cap performance monitoring is to ensure that physical and chemical isolation objectives are met over the long term. A more detailed description of each monitoring element is given in Appendix F.

The monitoring elements for each phase will require specific methods, equipment, and analyses to be applied at specified locations and frequencies over a predefined sampling grid of monitoring stations. Since the monitoring concerns are similar over the entire area to be capped, the monitoring station grid would be similar over the entire area. A preliminary layout of monitoring stations for a typical 300 by 600-m cap placement cell is shown in Figure 19.

The plan includes collection of physical, chemical, and biological data to address the processes of concern. More than one type of data can be collected with a given monitoring component or element. For example, SPC images provide both physical and biological data, and core samples can be analyzed to obtain physical, chemical, and biological data.

Physical processes of interest include the layering of capping material during placement, potential changes in cap thickness due to consolidation or currents and wave action (although no erosion is expected for caps placed in prisms A or B), and physical characteristics of the cap material such as porosity and grain size over time. The physical components of a monitoring plan needed to address these processes include sediment profile camera surveys, subbottom profiles, and physical analysis of core samples.

Chemical processes of interest include potential mixing of contaminated material with the clean capping material during the construction phase, in the long-term due to bioturbation, and the potential migration of contaminants upward through the cap due to consolidation or diffusion. The components of the monitoring plan addressing these processes include sediment cores for chemical analysis of sediment to define the chemical profile of the contaminated and clean capping layers. Additional cores taken over time at the same stations would detect any upward migration of contaminants.

Biological processes of interest include type/quantity of organisms which may recolonize the site and the bioturbation behavior of these organisms. Components of monitoring which address these processes include the chemical profiling and, depending on the outcome of that sampling, analysis of benthic organisms which colonize the site following completion of capping.

Testable hypotheses and tiers

Testable hypotheses for each element of the program are described in Appendix F. The appendix also includes a flowchart for each element indicating the appropriate monitoring tiers with thresholds, and additional monitoring requirements or management actions should the threshold be exceeded.

Management Actions

The results of monitoring conducted during cap placement need to be evaluated rapidly so that problems with materials or placement methods can be identified in time to effect the necessary changes. When any acceptable threshold values are exceeded, some type of management action is required. When the cap design is performing as expected, monitoring results can be used to optimize maintenance monitoring activities.

Specific management options are tied to testable hypotheses in Appendix F. The large area and volume of contaminated sediment involved, and the fact that the sediment is now in place on the shelf and exposed to the environment without a cap, influence the potential management actions. Those management actions considered appropriate for this project include an increase in the monitoring effort to a higher tier, use of alternate cap materials or placement methods, placement of additional cap thickness, and cessation of capping activities.

Monitoring Cost Estimates

An estimate of the monitoring costs associated with the various phases of the monitoring program was prepared by Dr. Tom Fredette, U.S. Army Engineer District, New England (CENAE). This estimate was based on conservative assumptions considering the vessel requirements and number of cells and stations within each cell which may be monitored, depending on the capping option selected for implementation. Actual monitoring costs would largely depend on the capping option selected and the sequence and timing of capping operations for specific cells. Essentially the same equipment and techniques are proposed for all phases of monitoring: subbottom profiling, SPC images, and cores. This allowed the cost estimates to be developed on a unit basis for each capping placement cell. Although the total number of cells for a given option would not necessarily be capped at the same time, this was assumed to be the case for purposes of the cost estimate. All estimated costs are in terms of present worth. A description of the basis for the cost estimate follows.

Vessel requirements

The survey vessel time will be a major component of the monitoring cost. The costs for vessel time were estimated on a unit basis for each cap cell monitored for appropriate components of the monitoring plan. For purposes of the cost estimate, a vessel size of 65-80 ft was used. The estimated vessel time does not include weather days. Daily costs included vessel, crew, fuel, mobilization/demobilization, equipment, scientific crew, data analysis, and data report. Vessel mob/demob cost can later be determined for specific vessels based in the region. Daily cost does not include full technical report with daily interpretation. Considering these factors, the estimated daily vessel cost is $10,000.

Baseline survey

A baseline survey including SPC images and core samples would establish conditions for each cap placement cell prior to cap placement. This baseline would be required for all cells for Options 1, 2 and 3. The layout of SPC image stations and core locations for both the baseline and routine construction monitoring is defined in Figure 19. The estimated vessel time for the baseline monitoring is :

Subbottom	0.5 days
SPC	0.4
Cores	0.1

Subtotal vessel = $10K
Analysis = $4K
Contingency 25% = $3.5K
Total per cell per survey = $17.5K

The large number of cells to be monitored for either of the options would allow for a factor of 0.90 (economy of scale) for a total unit monitoring cost of $15.5K per cell for the baseline surveys.

Initial cap placement monitoring

Cap construction monitoring would be conducted in a more detailed fashion for the first few cap placement cells. This effort includes the cap construction monitoring for cap thickness and extent plus the plume monitoring for sediment resuspension during cap placement. Although the layout of SPC image stations and core locations for routine construction monitoring is defined in Figure 19, the number of stations monitored for the initial construction monitoring would potentially be larger, depending on initial observations. This detailed initial survey

is assumed to be conducted for four cells for purposes of the cost estimate. The estimated vessel time for the initial construction monitoring is :

Subbottom profiling	3 days
SPC images	2
Cores	1
Plume monitoring	4
Subtotal 10 days = $100K	

The preliminary nature of work, and the need for flexibility, requires a high contingency, so a contingency of 50 percent was assumed, for a total cost of $150K for the four cells monitored.

Construction monitoring

The same monitoring components are required for the routine construction monitoring effort for each cell constructed. This effort would be required for all cells not already monitored during the initial construction monitoring effort. The estimated vessel time for the construction monitoring is the same as for the baseline and would include the same contingency and factor of 0.90 (economy of scale) for a total unit monitoring cost of $15.5K per cell. The cap material quality monitoring would be carried out as a part of the initial cap placement and construction monitoring, but this cost would be nominal and was not shown as a separate cost item.

Cap performance monitoring

The same monitoring components are required for the cap performance monitoring as for routine construction monitoring. For purposes of this estimate, it is assumed that this effort would would be required for all cells for options 1, 2, and 3 for four surveys occurring at 1 year, 2 years, 5 years, and 10 years following cap placement. If the results of initial surveys justify a reduction in the effort for later surveys, a smaller number of cells, randomly chosen, could be monitored, with a proportionate reduction in costs. The estimated vessel time for the cap performance monitoring is the same as for the baseline and construction phases and would include the same contingency and factor of 0.90 (economy of scale) for a total unit monitoring cost of $15.5K per cell.

Severe event response

In the event of a severe event, such as a major storm or earthquake, an additional monitoring effort, similar to a cap performance survey may be warranted. For purposes of this estimate, it is assumed that such an effort would be practically identical to a performance survey, and one such survey was included in the estimate.

Maintenance and management actions

No costs for future potential cap maintenance or additional monitoring or other management actions were included in these cost estimates.

Interpretation and reports

The above costs included a basic data report only. Interpretation of the data and a complete data analysis report would be required for each phase of the monitoring. There would also be need for coordination, briefings, etc. associated with the long-term monitoring program. These cost estimates included a lump sum of $500K for interpretation and reports. A summary of the monitoring costs is shown in Table 5.

6 Conclusions

Based on the results of this study, the following conclusions are made:

a. The overall conclusion from the previous NOAA study that in situ capping is a technically feasible alternative was confirmed by the more detailed and site specific evaluations of options for in situ capping conducted for this study.

b. The project conditions as defined by previous NOAA studies relating to site currents and waves, bathymetry, sediment physical properties, and distribution of contaminants were adequate for the evaluations conducted for this study.

c. The primary functions of an in situ cap for the PV shelf are:

> (1) physical isolation of the contaminated sediment from the benthic environment, reducing the exposure of organisms to contaminants and the potential bioaccumulation and movement of contaminants into the food chain,
>
> (2) reduction of the flux of dissolved contaminants into the water column, and
>
> (3) physical stabilization of the contaminated layer to retard resuspension due to currents and waves.

d. Two capping approaches may be considered for selected areas of the shelf:

> (1) thin cap - a cap of sufficient thickness to isolate the contaminated material from shallow burrowing benthic organisms (by far the majority of the organisms), providing a proportional reduction in the exposures and the flux of contaminants into the water column.
>
> (2) isolation cap - a cap of sufficient thickness to effectively prevent contaminant flux for the long term, isolate benthic organisms from the material, and prevent bioaccumulation of contaminants.

e. The available cap materials are varied, and final selection of capping materials for specific capping scenarios would depend on more detailed evaluations. However, it is assumed for purposes of this study that the available capping materials would be predominantly sandy sediments with a fraction of fine silt/clay. The most likely sources of cap material are dredged sediments from the Queen's Gate navigation channel deepening project and sand taken from borrow areas located outside the Los Angeles/ Long Beach harbor breakwater.

f. The potential for bioturbation at the site was considered in the cap design. Bioturbation processes were evaluated based on the known behavior and depth distribution of infaunal organisms likely to colonize the site in significant numbers. Most of the benthic organisms inhabiting the proposed project area are "shallow" bioturbators, with sediment mixing largely occurring within the uppermost 15 to 20 cm of the sediment column. A cap thickness component for bioturbation of 30 cm should accommodate most concerns related to bioturbation effects on cap integrity for areas selected for isolation by the cap. The potential for recolonization by deep bioturbators should be monitored.

g. The potential for erosion of the cap was evaluated using the LTFATE model. Based on these results, capping with fine sandy materials in water depths less than approximately 40 m would require consideration of additional cap thickness to offset potential storm induced erosion. No cap thickness component would be required for erosion for water depths exceeding about 40 m.

h. The seismic stability of a capped deposit was evaluated with the WESHAKE model. Results of this evaluation indicated that, for existing conditions without a cap, the contaminated sediments on slopes of up to 5 deg are not susceptible to flow failure if subjected to moderate earthquakes (magnitude 5.5 or greater). However, on the steeper slopes, the existing sediments are susceptible to flow failure under existing conditions. Addition of a cap with thickness up to 60 cm (approximately 2 ft) will not render the contaminated sediments susceptible to flow failure on slopes of 5 deg or less. However, addition of a cap of any thickness on slopes of 11 deg or greater will be susceptible to flow failure. Based on the distribution of slopes, areas deeper than the 70-m contour should not be considered for capping.

i. The erosion and seismic evaluations indicated that the shelf area lying between the 40-m and 70-m depth contours could be capped without special control measures. Two separate capping prisms, designated A and B, were defined between those depth contours.

j. Consolidation of the contaminated sediment layer was evaluated for the cap design. The layer will be compressed on the order of 10 percent of its thickness due to placement of a 45-cm (1.5-ft) cap. Changes for other cap thicknesses would be proportional. The cap thickness occupied by the expelled water was also

calculated, and the results showed that the water expelled by consolidation will easily remain within the cap thickness as placed.

k. An evaluation of the effectiveness of a cap to chemically isolate the contaminants was performed considering equilibrium partitioning principles and using the WES RECOVERY model. Placement of a 15-cm-thin cap over the contaminated sediments will not provide complete isolation from bioturbation/biodiffusion, and contaminants will be moved into the clean cap material by biodiffusion. Initial concentrations and flux are near zero and begin to increase immediately and reach a peak value in approximately 1,000 years. The peak fluxes and concentrations are reduced over 90 percent as compared to the no cap condition. Therefore, the thin cap provides significant isolation. Results for a 45-cm isolation cap showed essentially complete isolation for several hundred years, followed by very low flux for extremely long time periods, and a 45 cm total thickness was found be adequate for an isolation cap design.

l. A potential variation of 5 to 10 cm is considered a conservative estimate for operational tolerance for cap placement, allowing for some variation of the as-placed cap thickness and some mixing with the EA sediment. Because of the large area to be capped, this operational thickness component was not added to the design thickness; rather, the operational component was considered in evaluations of the isolation cap thickness requirements. Based on the relative effectiveness of 35- to 45-cm caps, the target cap thickness for placement of the isolation cap would be 45 cm, but areas later determined by monitoring to have thickness in excess of 35 cm would not require additional cap material. An operational tolerance in cap thickness was not considered appropriate for the thin cap design, because the intent of the thin cap is to provide a proportional reduction in exposures, not isolation.

m. Considering the two possible capping approaches of a thin cap or an isolation cap, and two capping prisms A and B, three capping options were selected for evaluation:

> Capping Option 1 - Placement of a 45 cm isolation cap over prisms A and B
>
> Capping Option 2 - Placement of a 15 cm thin cap over prisms A and B
>
> Capping Option 3 - Placement of a 15 cm thin cap only over prism A

Other capping and thickness options could be considered.

n. Reductions in the exposures of interest (sediment concentrations in the mixed layer, porewater concentrations in the mixed layer, and flux to the water column) were computed at 100 years following cap placement. Option 1 (45-cm isolation cap over prisms A and B) results in a reduction in potential exposures over the total shelf area on the order of 85 percent, option 2 (15-cm thin cap over prism A and B) results in reductions on the order of 75 percent, and option 3 (15-cm thin cap over prism A) results in reductions on the order of 65 percent. For these measures of exposure, capping additional surface area results in more reduction of exposure than additional cap thickness.

o. Hopper dredges are recommended as the equipment of choice for capping on the PV shelf for the following reasons:

> (1) Hopper dredges are the most likely type of equipment used to deepen and maintain the navigation channels in LA/LB harbor, a potential source for capping material.
>
> (2) Hopper dredges remove material from channels or borrow sites by hydraulic means, resulting in a breakdown of any hardpacked material and addition of water as material is stored in the hopper for transport. Material from hopper dredges is therefore more easily dispersed in the water column, and would therefore settle to the seafloor with less energy and less potential for resuspension of the contaminated sediment.

p. Cap placement modeling was conducted using the MDFATE model to define sediment placement scenarios which will produce the needed cap thickness. Results indicated that spreading placement methods in which the dredge gradually releases material would be appropriate for placement of sand from the borrow area sources. Conventional placement methods using a series of discrete releases along a system of placement lines or lanes would be appropriate for materials from the Queen’s Gate navigation channel.

q. The preferred sequence of placement of material can be defined by a series of cap placement cells 300 by 600 m. This sequence begins with the southeasternmost cell and progresses in order to the northwest. Such a sequence would result in the lowest potential for recontamination of the cap surface from adjacent areas since the prevailing currents are from southeast to northwest.

r. Monitoring is required to ensure that the cap is placed as intended and that the cap is performing the desired functions of physical isolation and reduction of contaminant flux. The monitoring program should focus on cap thickness, cap benthic recolonization, and physical and chemical characteristics of the cap over time. The principal monitoring approaches should include subbottom acoustic profiling, sediment core sampling, biological sampling, and sediment profile camera images.

s. Total costs for each option were estimated considering the total construction costs (with 50 percent contingency) and the monitoring costs. A lump sum cost for engineering design and a supervision and an administration cost of 6.3 percent were also considered in the total estimated costs. The areas, cap thicknesses, estimated volumes of material, and the estimated costs of these options are summarized in Table 6.

References

Allard, R., Farrar, P., Mark, D., Martin, J., Shapiro, B., Lowe, S., and Ko, D. S. (1996). “Creating a 4-D integrated scenario near Camp Pendelton CA,” Proceedings, Conference on Coastal Oceanic and Atmospheric Prediction, Am. Meteorological Soc., Boston, MA.

Boudreau, B. P. (1994). “Is burial velocity a master parameter for bioturbation?” *Geochemica et Cosmochemica Acta* 58. 1243-49.

Boyer, J. M., Chapra, S. C., Ruiz, C. E., and Dortch, M. S. (1994). “RECOVERY, a mathematical model to predict the temporal response of surface water to contaminated sediments,” Technical Report W-94-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Brannon, J. M., et al. (1985). "Effectiveness of capping in isolating contaminated dredged material from biota and the overlying water," Technical Report D-85-10, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Bokuniewicz, H. J., Gerbert, J., Gordon, R. B., Higgins, J. L., Kaminsky, P., Pilbeam, C. C., Reed, M., and Tuttle, C. (1978). "Field study of the mechanics of the placement of dredged material at open-water disposal sites," Technical Report D-78-7, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Di Toro, D. M., Jeris, J. S., and Clarcia, D. (1985). "Diffusion and partitioning of hexachlorobipheny in sediments," *Environmental Science and Technology*, 1(2), 1169-1176.

Drake, David E., Sherwood, Christopher R., and Wiberg, Patricia L. (1994). "Predictive modeling of the natural recovery of the contaminated effluent-affected sediment, Palos Verdes Margin, Southern California," Expert Report, Proposal for National Oceanic and Atmospheric Administration.

Environmental Protection Agency (1997). “Screening evaluation of response actions for contaminated sediment on the Palos Verdes Shelf,” Environmental Protection Agency, Region IX, San Francisco, CA.

Fredette, T. J. , Anderson, G., Payne, B. S., and Lunz, J. D. (1986). "Biological monitoring of open-water dredged material disposal sites", Proceedings, IEEE Oceans '86 Conference, Washington, DC.

Fredette, T. J., Nelson, D. A., Clausner, J. E., and Anders, F. J. (1990). "Guidelines for physical and biological monitoring of aquatic dredged material disposal sites," Technical Report D-90-12, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Griffis, R. B., and Chavez, F. L. (1988). “Effects of sediment type on burrows of *Callianassa californiensis* Dana and *C. gigas* Dana,” *Journal of Experimental Marine Biology and Ecology* 117, pp 239-53.

Headland, John R., Lesnik, John R., McNeilan, Thomas W., and Hooper, James R. (1994). "Feasibility study of sediment restoration alternatives for the southern california natural resource damage assessment, Appendix G: hydrodynamic and geotechnical assessment of the in situ capping alternative," Expert Report prepared for National Oceanic and Atmospheric Administration and the U.S. Department of Justice, Moffat and Nichol Engineers, Baltimore, MD.

Hill, D. O., Myers, T. E., and Brannon, J. M. 1988. "Development and application of techniques for predicting leachate quality in confined disposal facilities, background and theory," Miscellaneous Paper D-88-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Johnson, B. H., and Fong, M. T. (1993). “Development and verification of numerical models for predicting the initial fate of dredged material disposed in open water - report 2 - theoretical developments and verification results,” Dredging Research Program Technical Report DRP-93-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Los Angeles County Sanitation Districts (1996). “Annual ocean water quality and bottom monitoring report for 1995,” County Sanitation Districts of Los Angeles County, Los Angeles, CA.

Lee, H. J. (1994). "The distribution and character of contaminated effluent-affected sediment, Palos Verdes Margin, Southern California," Expert Report.

Lee, H. J. and McArthur, W. G. (1995) “Stability of sediment on the Palos Verdes Margin, Southern California,” DRAFT Final Report to the Los Angeles County Sanitation Districts, U.S. Geological Survey, Menlo Park, CA.

Lee, H. J., and McArthur, W. G. “Stability of sediment on the Palos Verdes Margin, Southern California,” In preparation report prepared by the U.S. Geological Survey for the Los Angeles County Sanitation Districts.

Luettich, R. A., Westerlink, J. J. and Scheffner, N. W. (1992). “ADCIRC: an advanced three-dimensional circulation model for shelves, coasts, and estuaries, report 1: theory and methodology of ADCIRC-2DDI and ADCIRC-3DL, Technical Report DRP-92-6, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Morris, P. A. (1994). “Potential large-scale bioturbation by the bat ray (*Myliobatis californica*) of the Palos Verdes Shelf sediments,” (CD Rom) Attachment E.A4, Southern California Bight Natural Resource Damage Assessment Data Files.

Niedoroda, A. W., Swift, D. J. P. Reed, C. W. and Stull, J. K. (1996). “Contaminant dispersal on the Palos Verdes Continental Margin: III. Processes controlling transport, accumulation and re-emergence of DDT-contaminated sediment particles,” *Science of the Total Environment* 179(1996), pp 109-33.

Ogden Environmental and Energy Services. (1994). “Bioturbation study for Convair Lagoon capping project” Contract report submitted to Teledyne Ryan Aeronautical, San Diego, CA.

Palermo, M. R. (1991). "Design requirements for capping," Dredging Research Technical Note DRP-5-03, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Palermo, M. R. (1994). "Feasibility study of sediment restoration alternatives for the Southern California natural resource damage assessment," Expert Report prepared for National Oceanic and Atmospheric Administration and the U.S. Department of Justice, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Palermo, M. R. (1998). “Design considerations for in situ capping of contaminated sediments,” *Water Science and Technology*, 37(6-7), pp 315-21.

Palermo, M. R., Fredette, T. J., and Randall, R. E., (1992). "Monitoring considerations for capping," Dredging Research Technical Notes, DRP-5-07, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Palermo, M. R., Miller, J., Maynord, S., and Reible, D. (1996). "Guidance for in situ subaqueous capping of contaminated sediments," EPA 905-B96-004, Prepared for the Great Lakes National Program Office, U.S. Environmental Protection Agency, Chicago, Ill.

Palermo, M., Clausner, J., Rollings, M., Williams, G., Myers, T., Fredette, T. and Randall, R. (1998). "Guidance for subaqueous dredged material capping," Technical Report DOER-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Pemberton, G. S., Risk, M. J. and Buckley, D. E. (1976). "Supershrimp: Deep bioturbation in the Strait of Canso, Nova Scotia," *Science* 192, pp 790-791

Port of Los Angeles. (1992). "Younger marine sands," excerpts from Report No. 0901-2027, Vol. 1, by Fugro-McClelland, provided by Mr. Richard Wittkop.

Randall, R. E., Clausner, J. E., and Johnson, B. H. (1994). "Modeling cap placement at New York mud dump site," *Proceedings of Dredging '94*, American Society of Civil Engineers, New York, pp 1295-1304.

Rhoads, D. C., and Carey, D. A. (1996). "Capping dredged materials in the New York Bight: Evaluation of the effects of bioturbation," Science Applications International Corporation Report No. 374, Report No. 39 of the New York Mud Dump Site Studies, submitted to the U.S. Army Corps of Engineers New York District.

Scheffner, N. W. (1991a). "A generalized approach to site classification - dispersive or non-dispersive," Dredging Research Information Exchange Bulletin Vol. DRP-91-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Scheffner, N. W. (1991b). "A systematic analysis of disposal site stability," Proceedings of the Coastal Sediments 91, American Society of Civil Engineers, Seattle, WA.

Scheffner, N. W., (1996). "Systematic analysis of long-term fate of disposed dredged material," *J. Waterways, Harbors and Coastal Eng. Div. Am. Soc. Civ. Eng.* 122(3).

Scheffner, N. W., Thevenot, M. M., Tallent, J. R. and Mason, J. M. (1995). "LTFATE: A model to investigate the long-term fate and stability of dredged material disposal sites; User's guide," Dredging Research Program Instruction Report DRP-95-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Schnabel, P. B., Lysmer, J. and Seed, H. B. (1972). "SHAKE A computer program for earthquake response analysis of horizontally layered sites," EERC Report No. 72-12, University of California, Berkeley.

State of California. (1983). “Potential offshore sand and gravel resources of the inner continental shelf of Southern California,” Department of Boating and Waterways, State of California.

Stull, J. K., Haydock, C. I. Smith, R. W. and Montagne, D. E. (1986). “Long-term changes in the benthic community on the coastal shelf of Palos Verdes Southern California,” Marine Biology 91:53-551.

Stull, J. K., Irwin, C., and Montagne, D. E. (1986). “Effects of Listriolobus (Echiura) on coastal shelf benthic communities and sediments modified by a major California wastewater discharge,” *Estuarine, Coastal and Shelf Science*, 22, pp 1-17

Stull, J. K., Swift, D. J. P., and Niedoroda, A. W. (1996a). “Contaminant dispersal on the Palos Verdes continental margin: I. Sediments and biota near a major California wastewater discharge,” *The Science of the Total Environment*, 179(1996):73-90

____. (1996b). “Contaminant dispersal on the Palos Verdes Continental Margin: II. Estimates of the biodiffusion coefficient, D_b, from composition of the benthic infaunal community,” *Sci. Total Environment*, 179(1996):91-107.

____. (1996c). “Contaminant Dispersal on the Palos Verdes Continental Margin: III. Processes controlling transport, accumulation and re-emergence of DDT-contaminated sediment particles,” *Sci. Total Environment*, 179,109-133.

Sykora, D. W. (1987). “Creation of a data base of seismic shear wave velocities for correlation analysis,” Miscellaneous Paper GL-87-26, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Sykora, D. W., Wahl, R. E., Wallace, D. C. and Yule, D. E. (1994). “USACE geotechnical earthquake engineering software, report 2: WESHAKE for personal computers,” Instruction Report GL-94, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Thibodeaux, L.J., Valsaraj, K.T., and Reible, D.D. (1994). “Capping contaminated sediments - The theoretical basis and laboratory experimental evidence for chemical containment,” *Dredging ‘94*, Proceedings, Second International Conference on Dredging and Dredged Material Placement, Vol 2, pp 1001-7.

Truitt, C. L. (1986). "Fate of dredged material during open water disposal," Environmental Effects of Dredging Programs Technical Note EEDP-01-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

USACE/EPA. (1998). "Evaluation of dredged material proposed for discharge in waters of the U.S. - Testing manual (inland testing manual)," EPA-823-B-98-004, U.S. Environmental Protection Agency and US Army Corps of Engineers, Washington, DC.

Welch, T. (1993). "Cost estimates and capping material sources for Montrose project," Memorandum CESPL-CO-R dated 6 October 1993, U.S. Army Engineer District, Los Angeles, CA.

Wheatcroft, R.A. and Martin, W.R. (1994). “Predictive modeling of the natural recovery of the contaminated effluent-affected sediment, Palos Verdes Margin, Southern California: Appendix E: Solid phase Bioturbation Processes on the Palos Verdes Shelf,” Woods Hole Oceanographic Institution, Woods Hole, MA.

Table 1
Average DDT and PCB Sediment Concentrations, Pore water Concentrations, and Flux at 100 Years with Area-Weighted Reductions for Capping Options 1 Through 3

Average Concentration	Total shelf, no cap	Shelf less Prism A, no cap	Shelf less Prisms A & B no cap	Option 1 Prisms A&B 45 cm cap			Option 2 Prisms A&B 15 cm cap			Option 3 Prism A 15 cm cap		
				Prism A&B	Shelf Avg[1]	Reduction[2] %	Prism A&B	Shelf Avg[1]	Reduction[2] %	Prism A	Shelf Avg[1]	Reduction[2] %
Area, sq km	12.6[3]	7.7	5.0	7.6			7.6			4.9		
Avg DDT Sed Conc, mg/kg	7.70 E00	2.63 E00	2.06 E00	4.65 E-14	8.17 E-01	89	3.86 E-01	1.05 E00	86	4.46 E-01	1.78 E00	77
Avg DDT Pore Water Conc, mg/l	1.40 E-04	7.71 E-05	6.47 E-05	2.67 E-18	2.57 E-05	82	2.17 E-05	3.88 E-05	72	2.49 E-05	5.68 E-05	59
Avg DDT Flux, mg/m^2/year	7.4 E-02	3.03 E-02	2.21 E-02	5.11 E-16	8.77 E-02	88	4.15 E-03	1.12 E-02	85	4.77 E-03	2.03 E-02	72
Avg DDT Flux, mg/m^2/year (GIS value)	8.4 E-02	5.4 E-02	5.2 E-02	2.23 E-15	2.06 E-02	76	--------	------	--------	-------	------	--------
Avg PCB Sed Conc	7.73 E-01	2.92 E-01	2.33 E-01	2.08 E-16	9.25 E-02	88	3.47 E-02	1.13 E-01	85	3.84 E-02	1.93 E-01	75
Avg PCB Pore Water Conc	1.41 E-05	8.45 E-06	7.23 E-06	1.17 E-20	2.87 E-06	80	2.72 E-06	4.51 E-06	68	3.19 E-06	6.40 E-06	55
Avg PCB Flux	7.25 E-03	3.28 E-03	2.45 E-03	2.23 E-18	9.72 E-04	87	5.21 E-04	1.29 E-03	82	6.10 E-04	2.24 E-03	69

Note: All Table values are averages of all stations within the stated areas with the exception of the indicated entries for GIS computed averages
[1] Average values shown for Options 1, 2, and 3 are area-weighted shelf-wide averages with cap in place.
[2] Percent reductions calculated based on area-weighted shelf-wide averages with cap and shelf-wide values with no cap.
[3] Area for shelf less than 70 m depth contour.

Table 2
Summary of Cap Placement Operational Requirements

Capping Requirements	Option 1		Option 2		Option 3	
Capping prisms and thickness	Prism A & B 7.6 sq km 45-cm cap	Prism A & B 7.6 sq km 45-cm cap	Prism A & B 7.6 sq km 15-cm cap	Prism A & B 7.6 sq km 15-cm cap	Prism A 4.9 sq km 15-cm cap	Prism A 4.9 sq km 15-cm cap
Cap material source	Queen’s Gate	Sand Borrow	Queen’s Gate	Sand Borrow	Queen’s Gate	Sand Borrow
Total hopper volume	7,285,000 m^3 (9,527,000 yd^3)	5,882,000 m^3 (7,694,000 yd^3)	2,428,000 m^3 (3,176,000 yd^3)	1,961,000 m^3 (2,565,000 yd^3)	1,566,000 m^3 (2,047,000 yd^3)	1,264,000 m^3 (1,653,000 yd^3)
Total in-source volume	5,335,000 m^3 (6,978,000 yd^3)[1]	5,335,000 m^3 (6,978,000 yd^3)	1,778,000 m^3 (2,326,000 yd^3)	1,778,000 m^3 (2,326,000 yd^3)	1,147,000 m^3 (1,499,000 yd^3)	1,147,000 m^3 (1,499,000 yd^3)
Estimated number of hopper loads[2]	5,293	4,274	1,764	1,425	1,137	918
Number of construction seasons[2]	3.3	2.7	1.1	0.9	0.7	0.6

[1] The volume to be removed from Queen’s Gate for navigation improvements is approximately 6 million cubic yards in-source or 8,190,000 yd^3 in-hopper. The balance was assumed taken from overdredging in the Queen’s Gate channel.
[2] The estimated number of hopper loads and number of construction seasons are based on use of a single hopper dredge with 1,800 yd^3 loaded hopper capacity with an average of 1600 hopper loads placed during a 300 day annual construction season.

Table 3
Estimates of Total Cost for Cap Construction for Capping Options 1 Through 3

	Option 1		Option 2		Option 3	
Capping Requirements	Low range cost	High range cost	Low range cost	High range cost	Low range cost	High range cost
Capping prisms and thickness	Prism A & B 7.6 sq km 45-cm cap	Prism A & B 7.6 sq km 45-cm cap	Prism A & B 7.6 sq km 15-cm cap	Prism A & B 7.6 sq km 15-cm cap	Prism A 4.9 sq km 15-cm cap	Prism A 4.9 sq km 15-cm cap
Cap material source	Queen's Gate	Sand Borrow	Queen's Gate	Sand Borrow	Queen's Gate	Sand Borrow
Total hopper volume required	9,527,000 yd^3	7,694,000 yd^3	3,176,000 yd^3	2,565,000 yd^3	2,047,000 yd^3	1,653,000 yd^3
Unit cost	\$1.79/yd^3 and \$ 4.69/yd^3 [1]	\$4.78/yd^3	\$1.79/yd^3	\$4.99/yd^3	\$1.79/yd^3	\$5.06/yd^3
Total cap placement cost	\$20.9M	\$36.8M	\$5.7M	\$12.8M	\$3.7M	\$8.4M
Contingency	50%	50%	50%	50%	50%	50%
Total construction cost (Including 50% contingency)	\$31.4M	\$55.2M	\$8.5M	\$19.2M	\$5.5M	\$12.5M

[1] The volume to be removed from Queen's Gate for navigation improvements is approximately 6 million cubic yards in-source or 8,190,000 yd^3 in-hopper. The cost estimate reflects prorated unit costs based on using 8,190,000 yd^3 at \$1.79/cy and the balance of 1,337,000 yd^3 at \$4.69/yd^3.

Table 4
Monitoring Phases and Elements

Monitoring Phase	Element	Component	Analysis	Frequency/ Location
Cap construction	Cap material quality	Barge sampling	Physical properties	5% of hopper loads
	Cap thickness and extent	Sub-bottom profile	Layer thickness	Baseline/ initial placement/ final surveys over entire area
		SPC	Layer thickness	Baseline/ Initial placement/ Defined grid for remaining cells
		Cores	Layer thickness and physical properties	Defined grid
	Sediment resuspension	Plume tracking ADCP Water column samples	Suspended sediment; Water Column Chemistry	Detailed effort first cell/ water samples 2% of remaining hopper loads
Cap Performance	recolonization	SPC	Layer thickness/ recolonization	Defined grid at 1 year
	Physical isolation	Sub-bottom profile	Layer thickness	surveys over entire area at years 1, 5, 10
	Chemical isolation	Cores	Geology/ physical properties/ chemistry	defined grid at 1, 5, and 10 years
Severe event response	Cap integrity	Sub-bottom profile, SPC and cores		following major storms or earthquakes

Table 5
Summary of Monitoring Costs

Monitoring Phase	Option 1 or 2	Option 3	Frequency
Baseline Survey	56 cells@$15.5K= $868K	37 cells@$15.5K= $574K	Once
Initial Construction	4 cells with total $150K	4 cells with total $150K	Once
Construction	52 cells@$15.5K= $806K	33 cells@$15.5K= $512K	Once
Cap Performance/ Severe Event Response	56 cells/ 5 surveys @ $15.5K= $4.34M	37 cells/ 5 surveys @ $15.5K = $2.868M	Perf. surveys at 1, 2, 5, and 10 years plus one severe event survey
Interpretation/ Reports	Lump sum $500K	Lump sum $500K	After baseline, after construction, and after surveys at 1, 2, 5, and 10 years
Total	Approx. $6.7M	Approx. $4.6M	

Table 6
Summary of Areas, Thicknesses, Volumes and Costs for Capping Options 1 Through 3

	Option 1		Option 2		Option 3	
Capping Requirements	Low range cost	High range cost	Low range cost	High range cost	Low range cost	High range cost
Capping prisms and thickness	Prism A & B 7.6 sq km 45-cm cap	Prism A & B 7.6 sq km 45-cm cap	Prism A & B 7.6 sq km 15-cm cap	Prism A & B 7.6 sq km 15-cm cap	Prism A 4.9 sq km 15-cm cap	Prism A 4.9 sq km 15-cm cap
Cap material source	Queen's Gate	Sand Borrow	Queen's Gate	Sand Borrow	Queen's Gate	Sand Borrow
Total Hopper Volume	7,285,000 m^3 (9,527,000 yd^3)	5,882,000 m^3 (7,694,000 yd^3)	2,428,000 m^3 (3,176,000 yd^3)	1,961,000 m^3 (2,565,000 yd^3)	1,566,000 m^3 (2,047,000 yd^3)	1,264,000 m^3 (1,653,000 yd^3)
Total in-source volume	5,335,000 m^3 (6,978,000 yd^3)	5,335,000 m^3 (6,978,000 yd^3)	1,778,000 m^3 (2,326,000 yd^3)	1,778,000 m^3 (2,326,000 yd^3)	1,147,000 m^3 (1,499,000 yd^3)	1,147,000 m^3 (1,499,000 yd^3)
Total construction cost (including 50% contingency)	$31.4M	$55.2M	$8.5M	$19.2M	$5.5M	$12.5M
Monitoring costs	$6.7M	$6.7M	$6.7M	$6.7M	$4.6M	$4.6M
Maintenance costs	none	none	none	none	none	none
Engineering design*	$1M	$1M	$1M	$1M	$1M	$1M
Supv and admin (6.3%)	$2.5M	$4.0M	$1.0M	$1.7M	$0.7M	$1.1M
Total Cost	$41.6M	$66.9M	$17.2M	$28.6M	$11.8M	$19.2M

Note: All costs rounded to nearest $0.1M.
* Engineering design costs are assumed essentially equivalent. The estimated cost is based on previous experience with large scale projects.

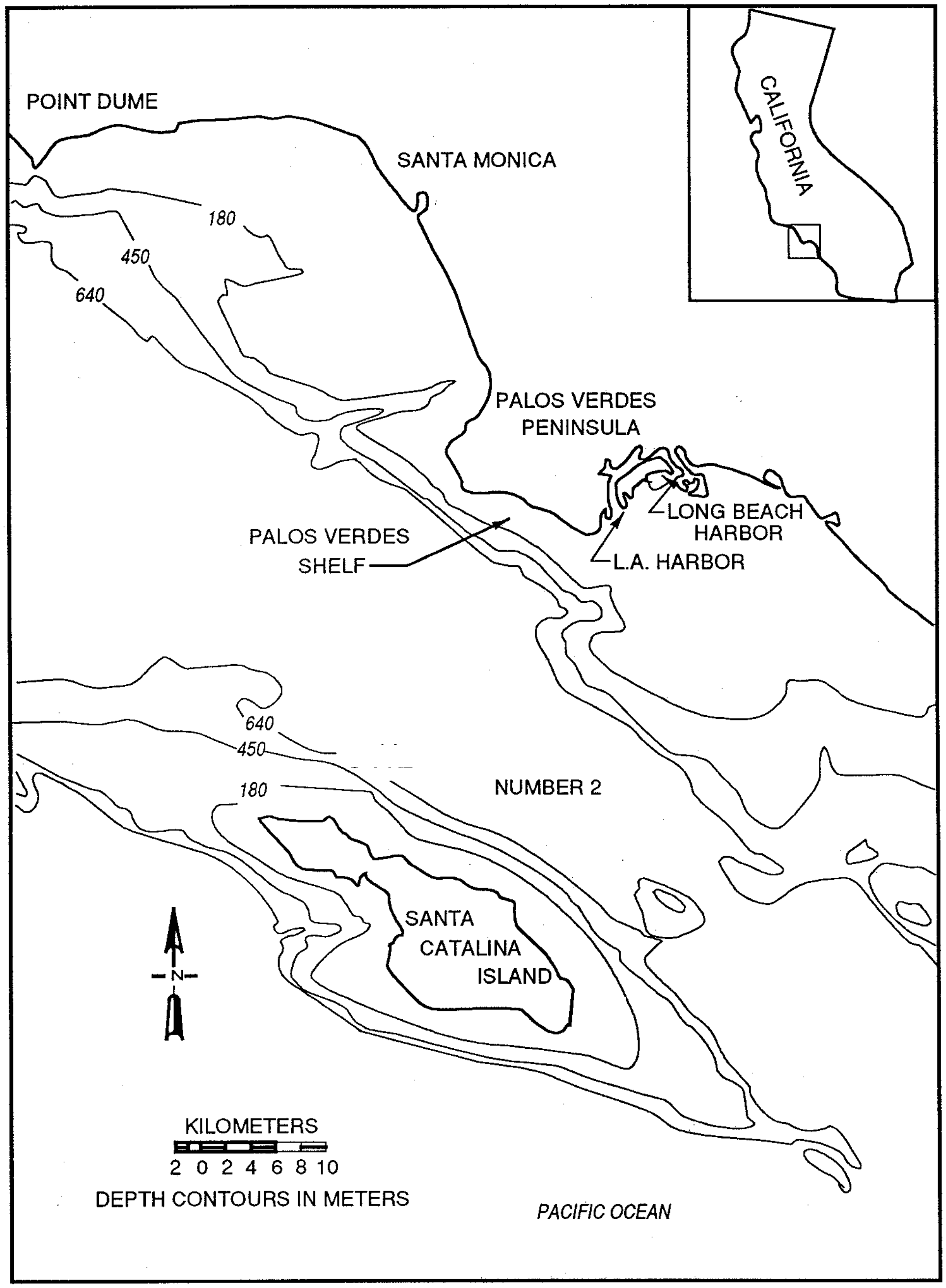


Figure 1. Location map of the Los Angeles Region Showing the Palos Verdes Shelf

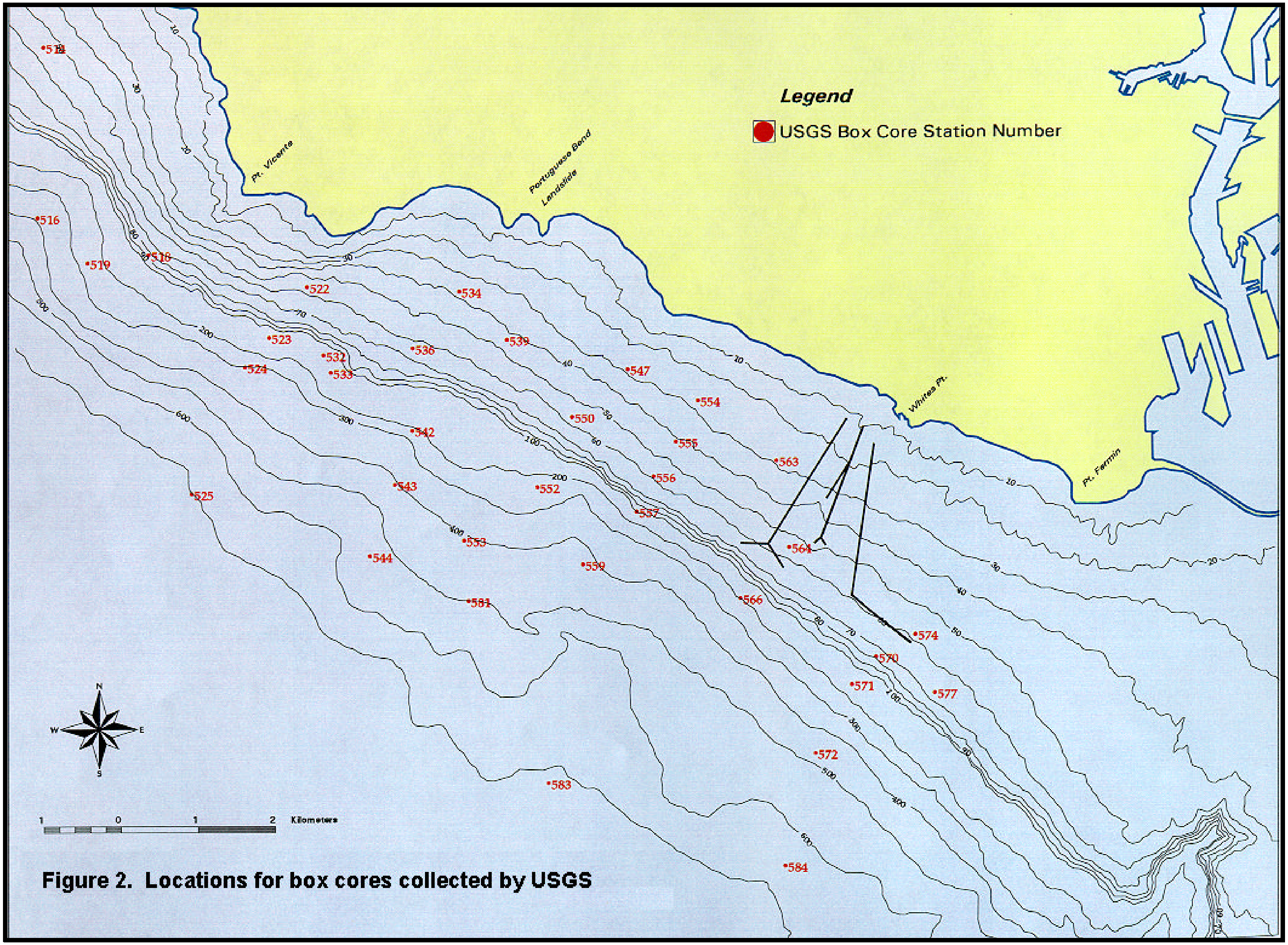


Figure 2. Locations for box cores collected by USGS

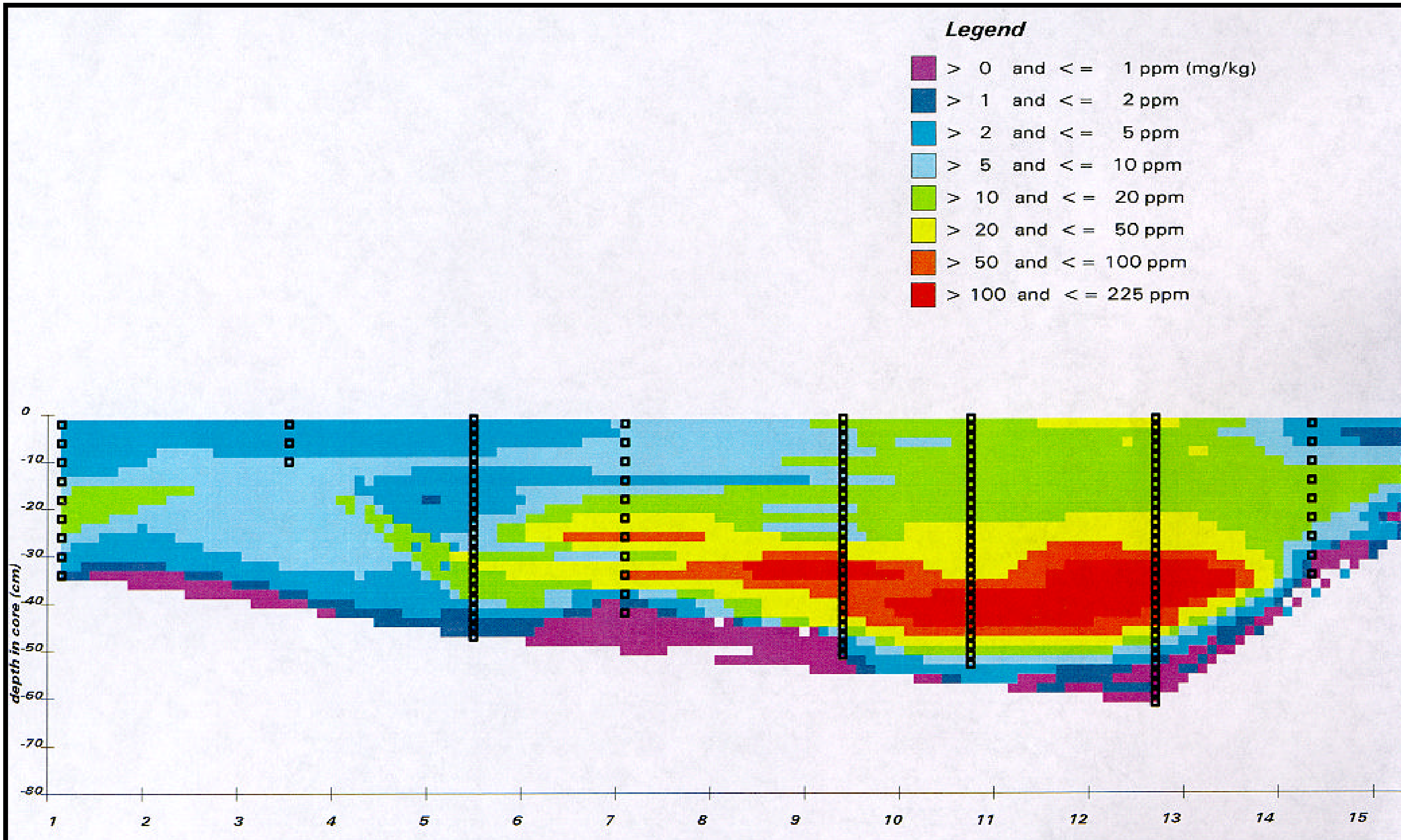


Figure 3. Profile of DDT for a typical alongshore cross section

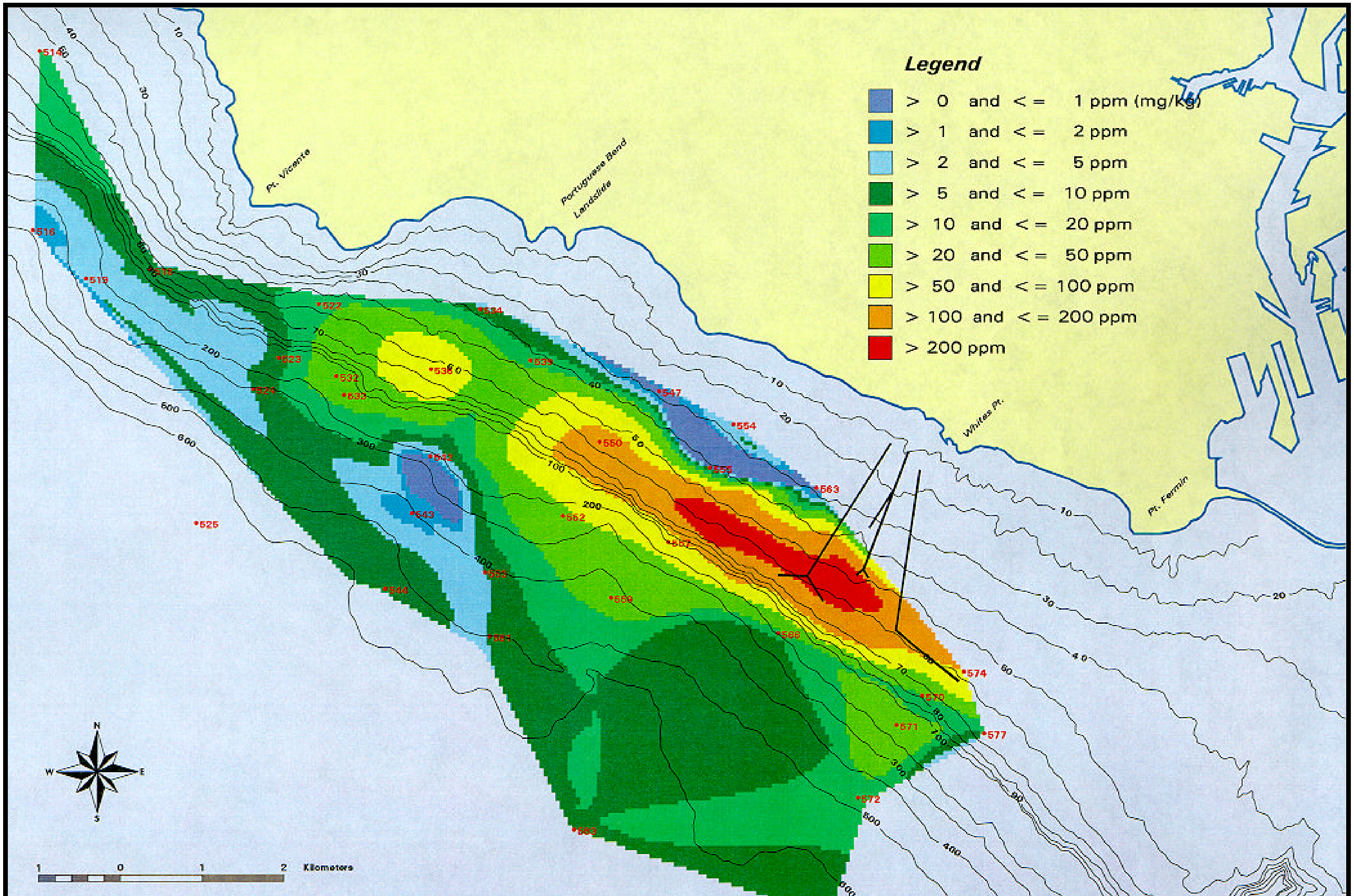


Figure 4. Map showing maximum sediment concentration of total DDT at any 4-cm depth increment

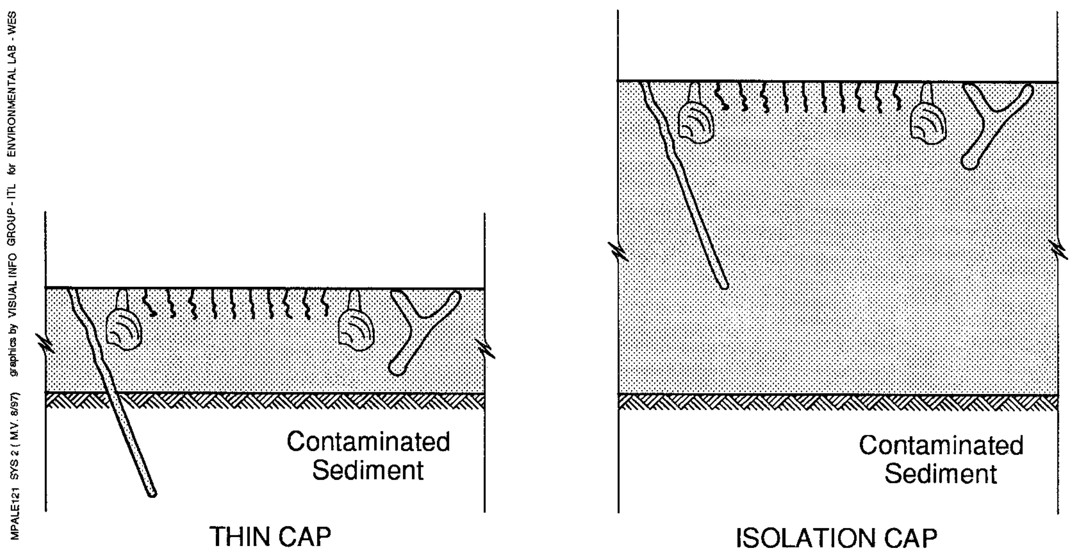


Figure 5. Conceptual illustration of thin cap and isolation cap

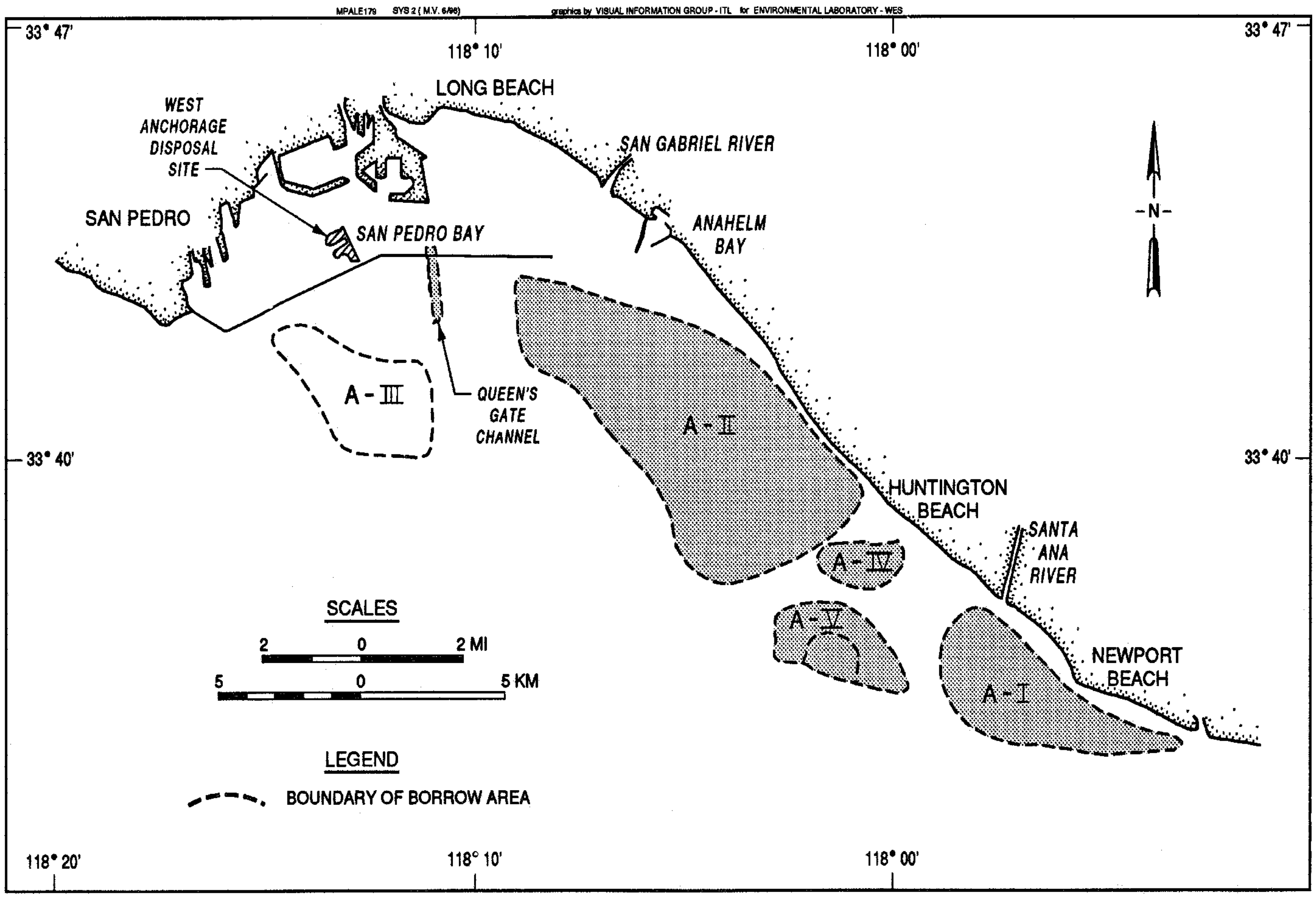


Figure 6. Map showing potential cap material sources

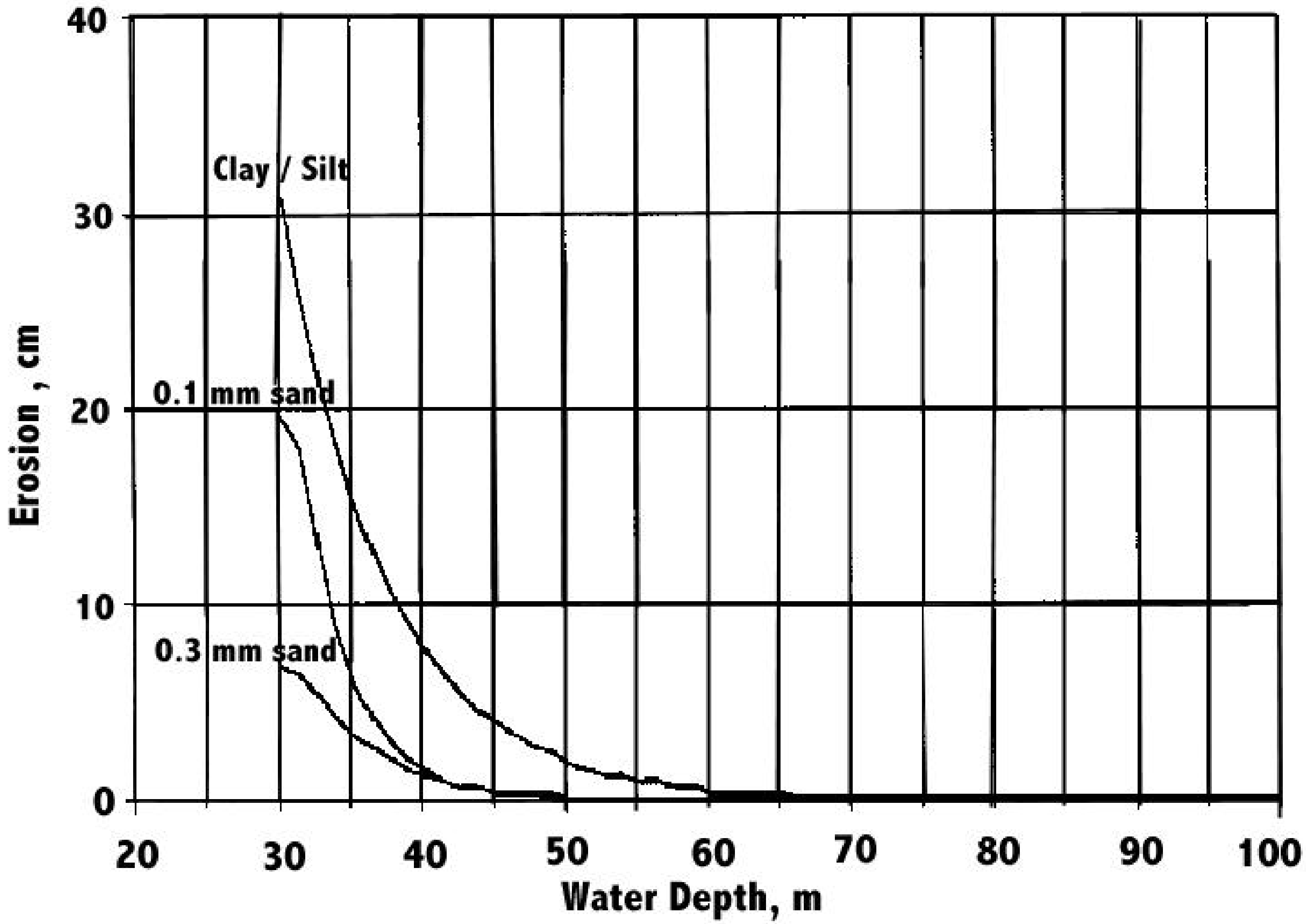


Figure 7. Plot of erosion versus water depths for severe storm event generating a 5.5-m wave height

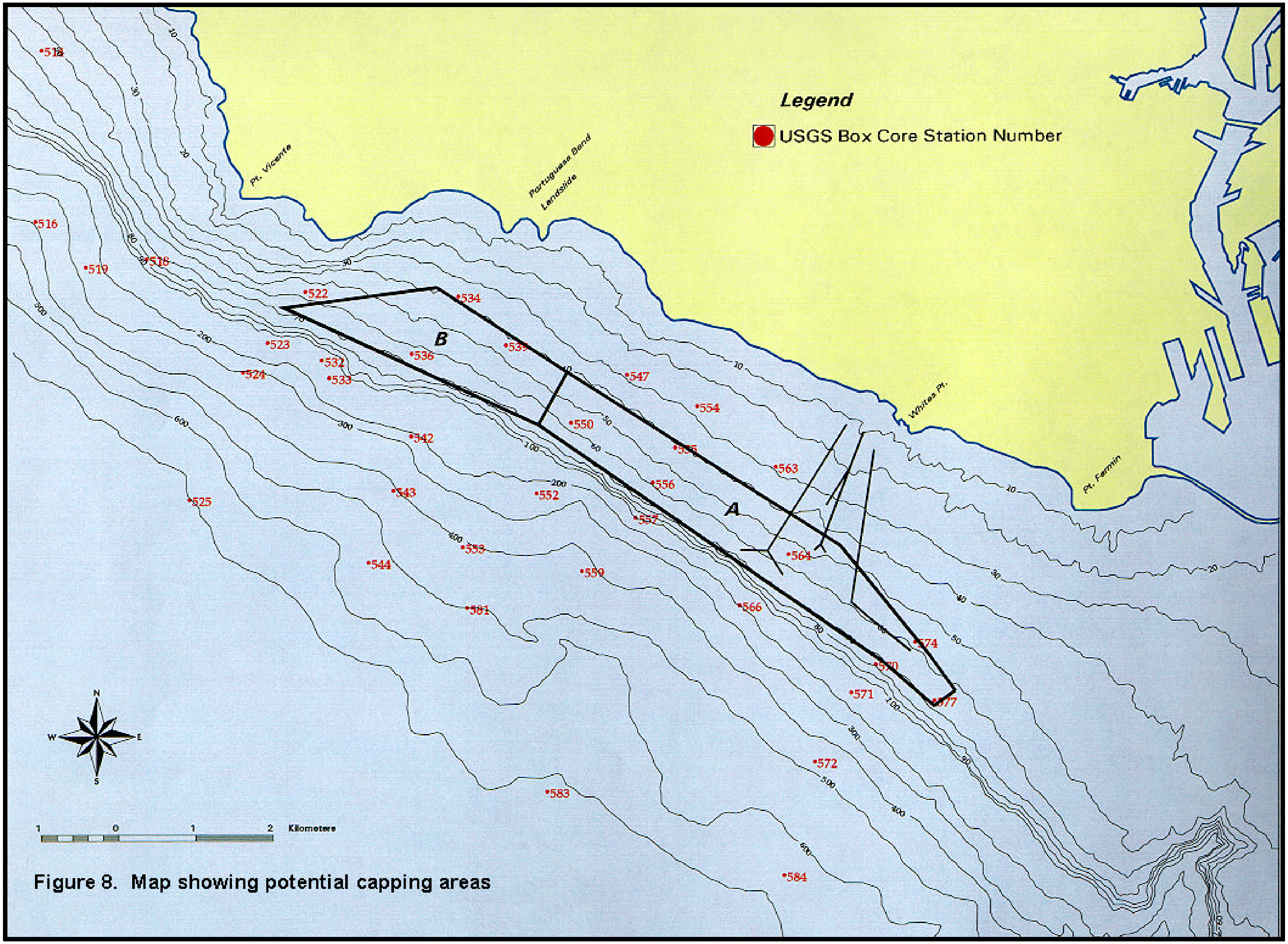


Figure 8. Map showing potential capping areas

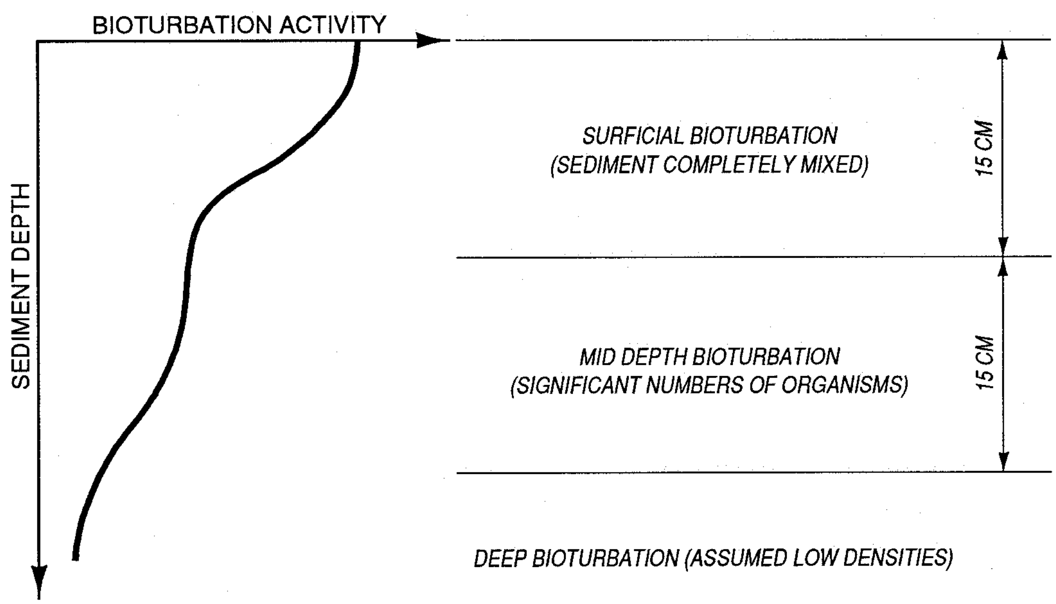


Figure 9. Illustration of zones of bioturbation

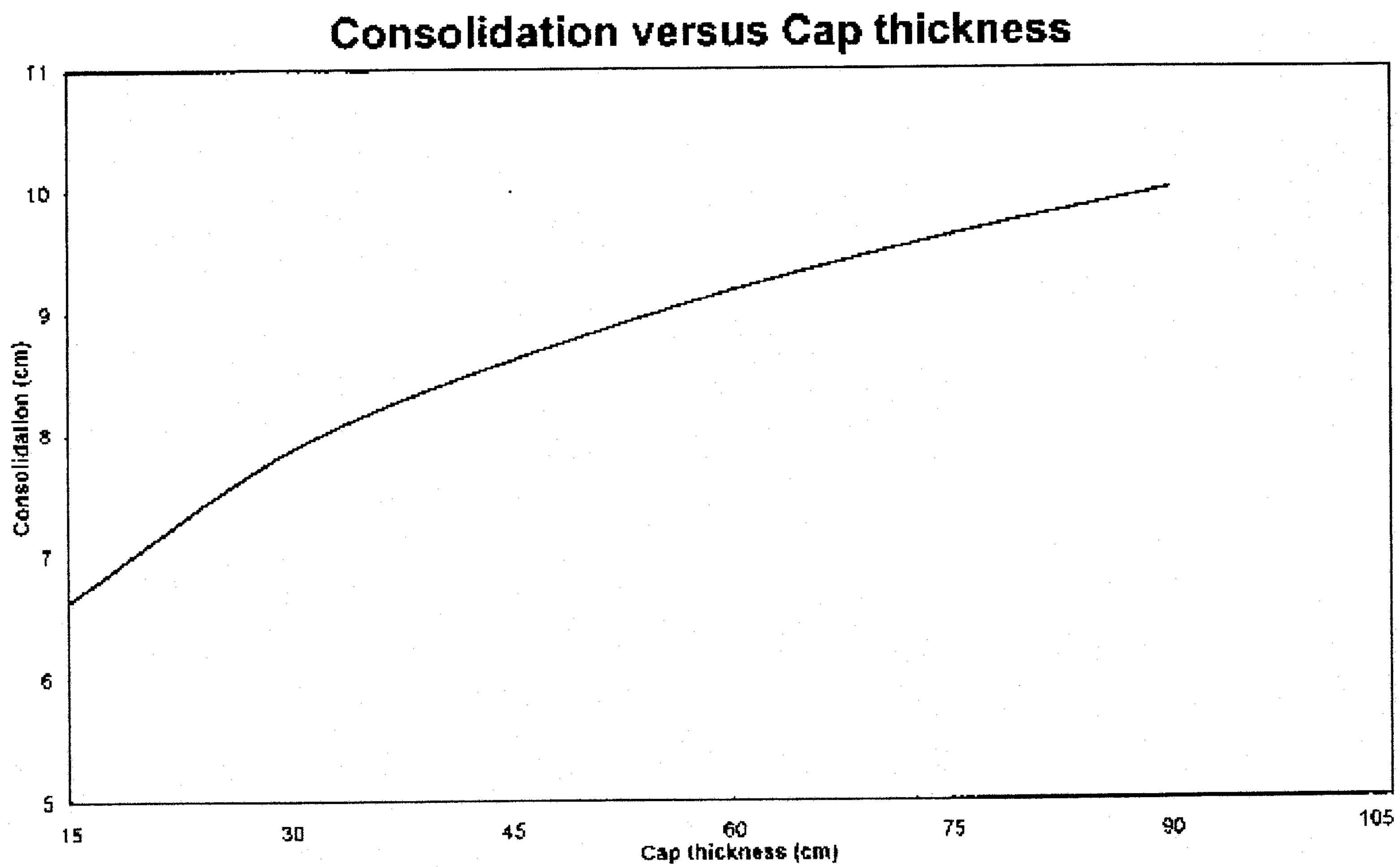


Figure 10. Total consolidation of effluent-affected sediment versus applied cap thickness for Station 557

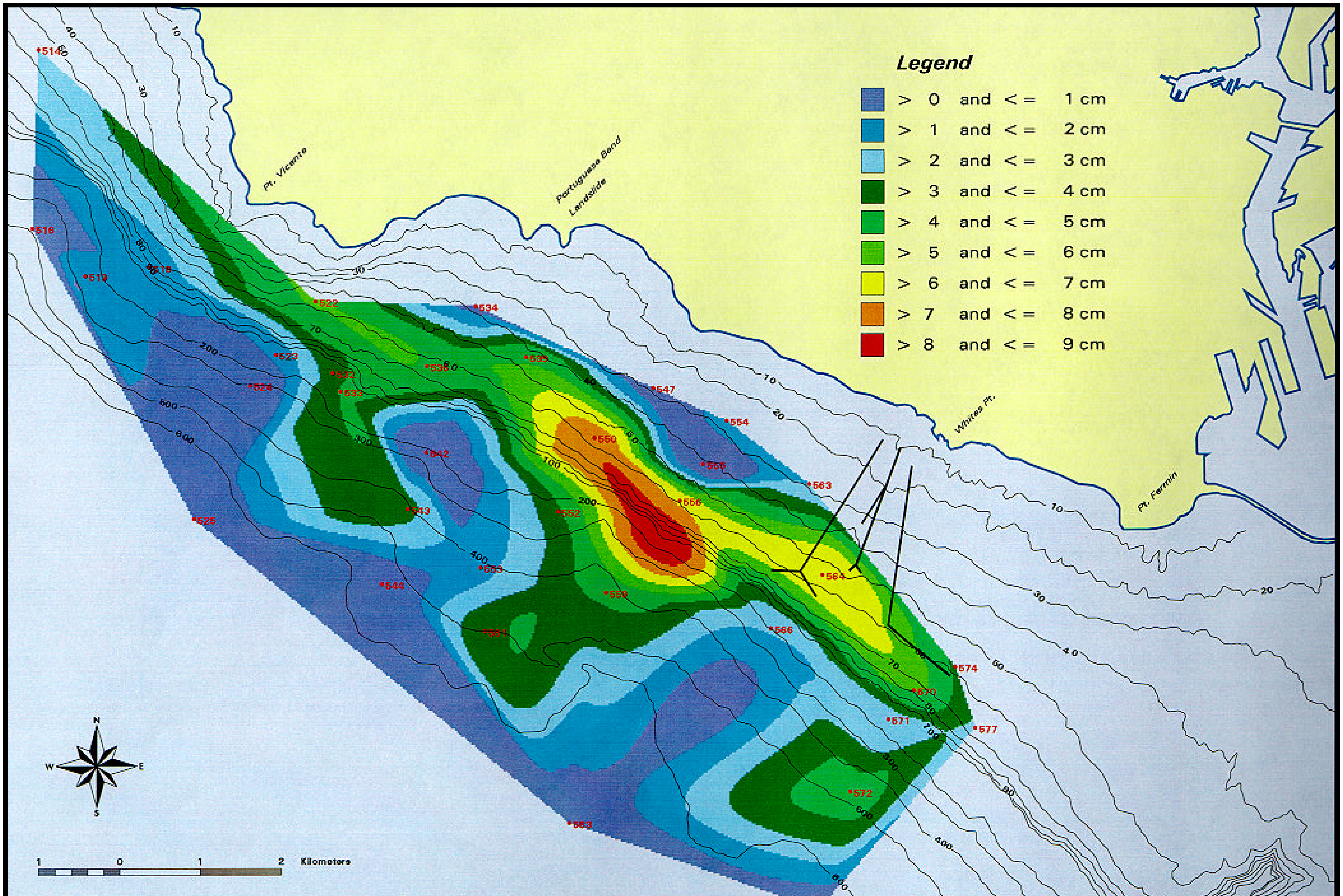


Figure 11. Map of consolidation for 45-cm cap

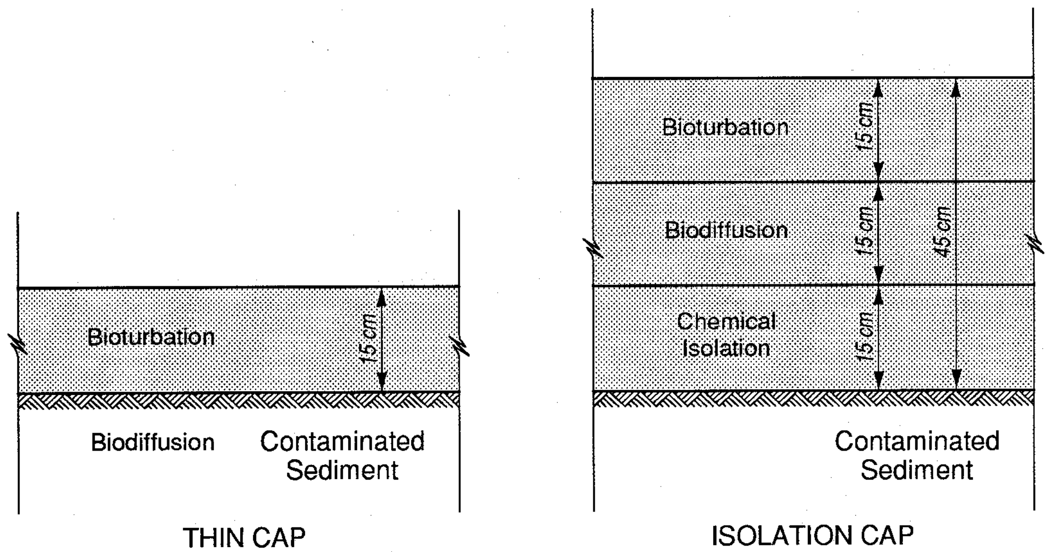


Figure 12. Illustration of recommended cap thickness for thin and isolation caps

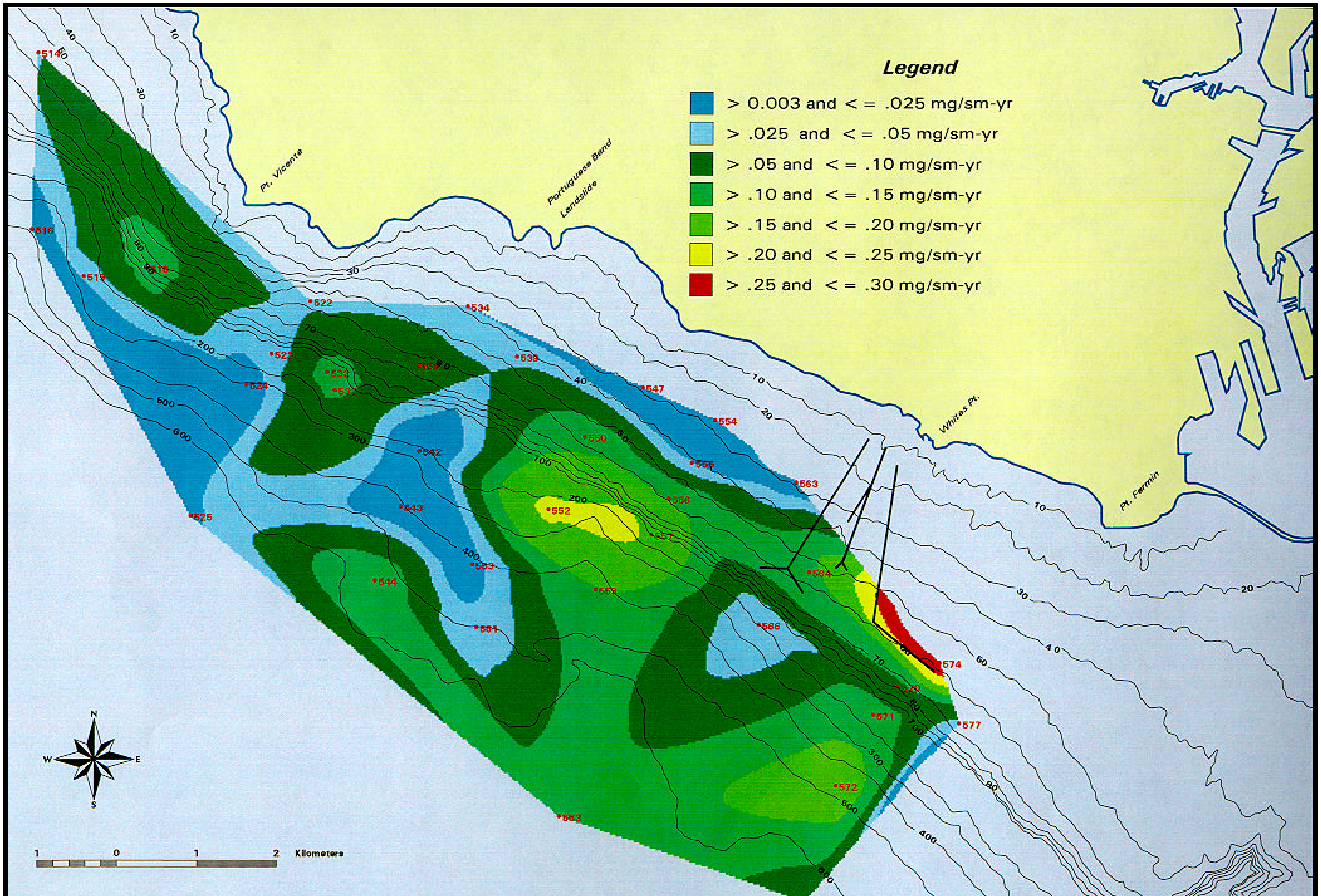


Figure 13. Map of DDT flux for the no cap option

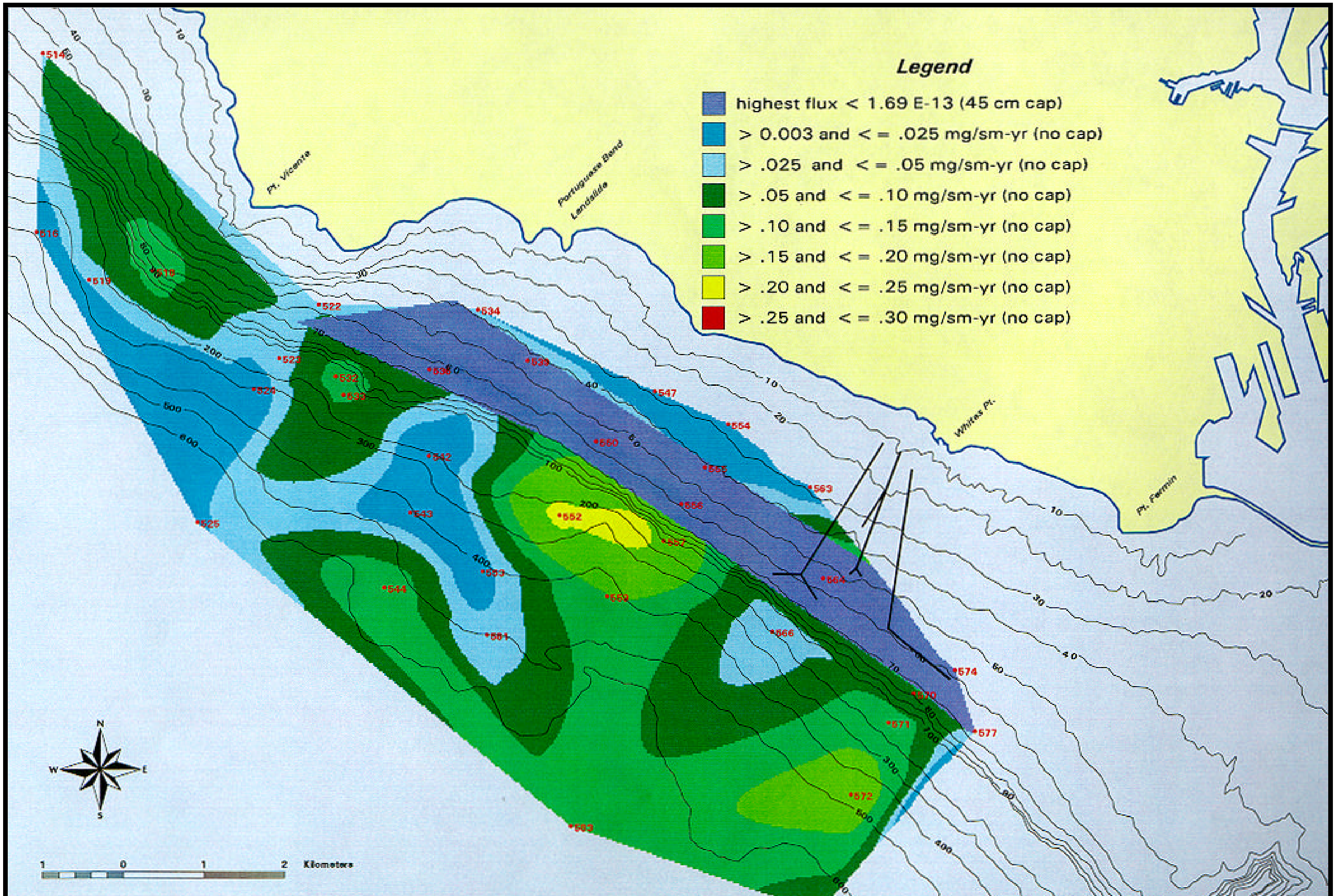


Figure 14. Map of DDT flux for the 45-cm cap option

Figure 15. Photo of a Manhattan Island class hopper dredge

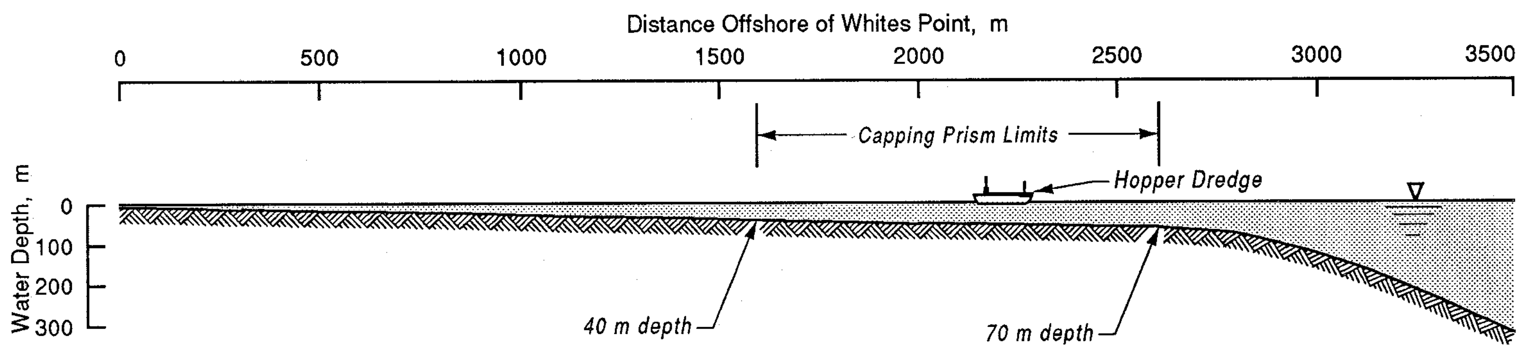


Figure 16. Scaled illustration showing relative size of hopper dredge in water depths of 40 to 100 m

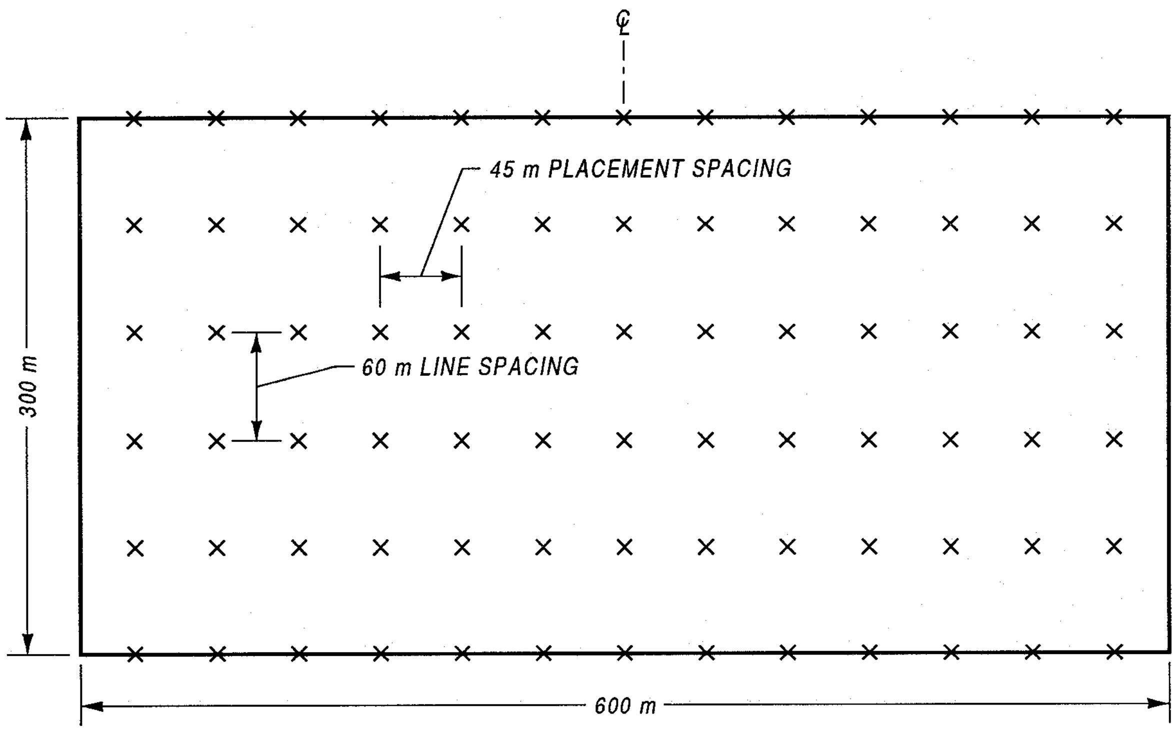


Figure 17. Illustration of placement lanes for typical grid

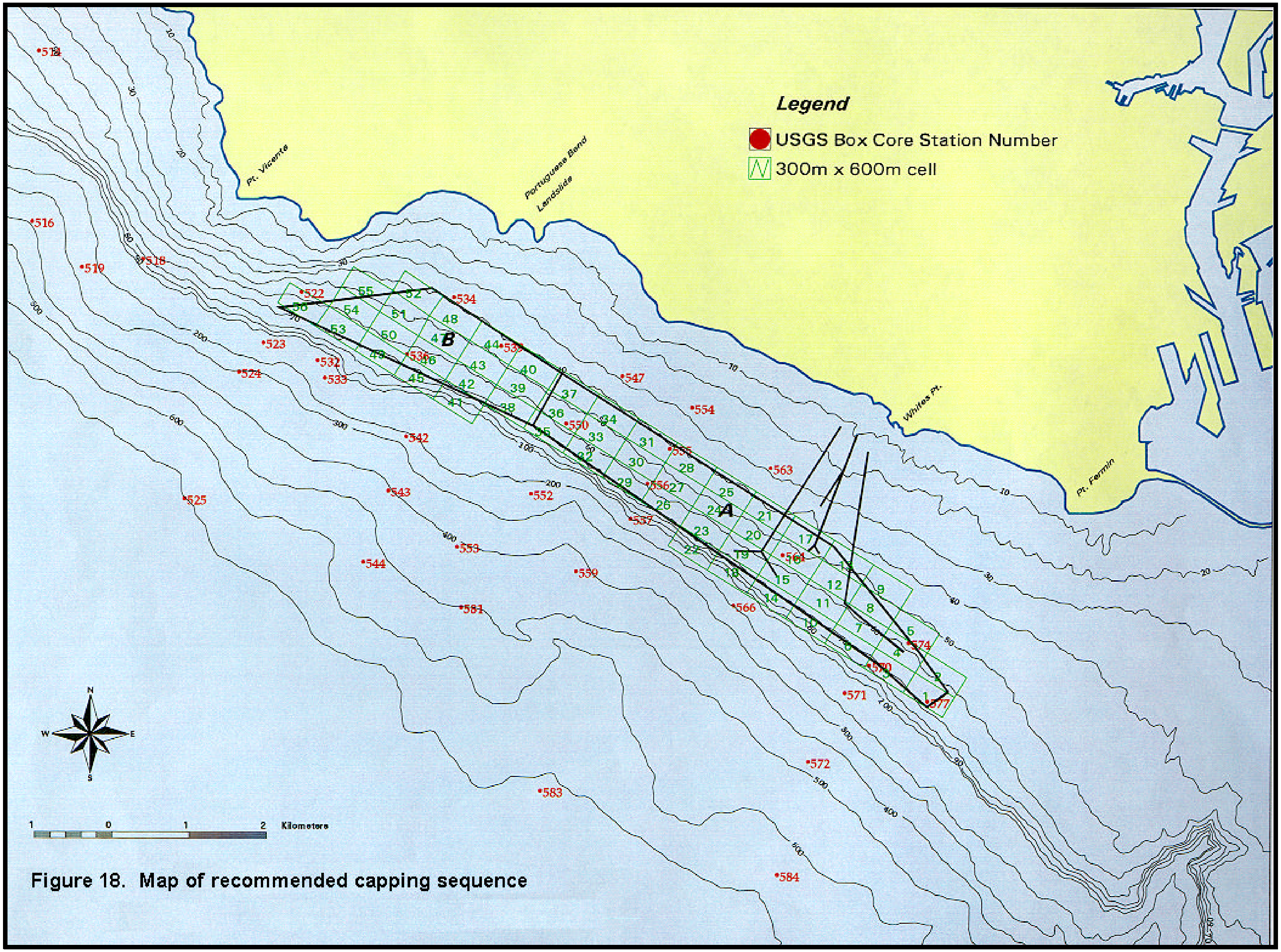


Figure 18. Map of recommended capping sequence

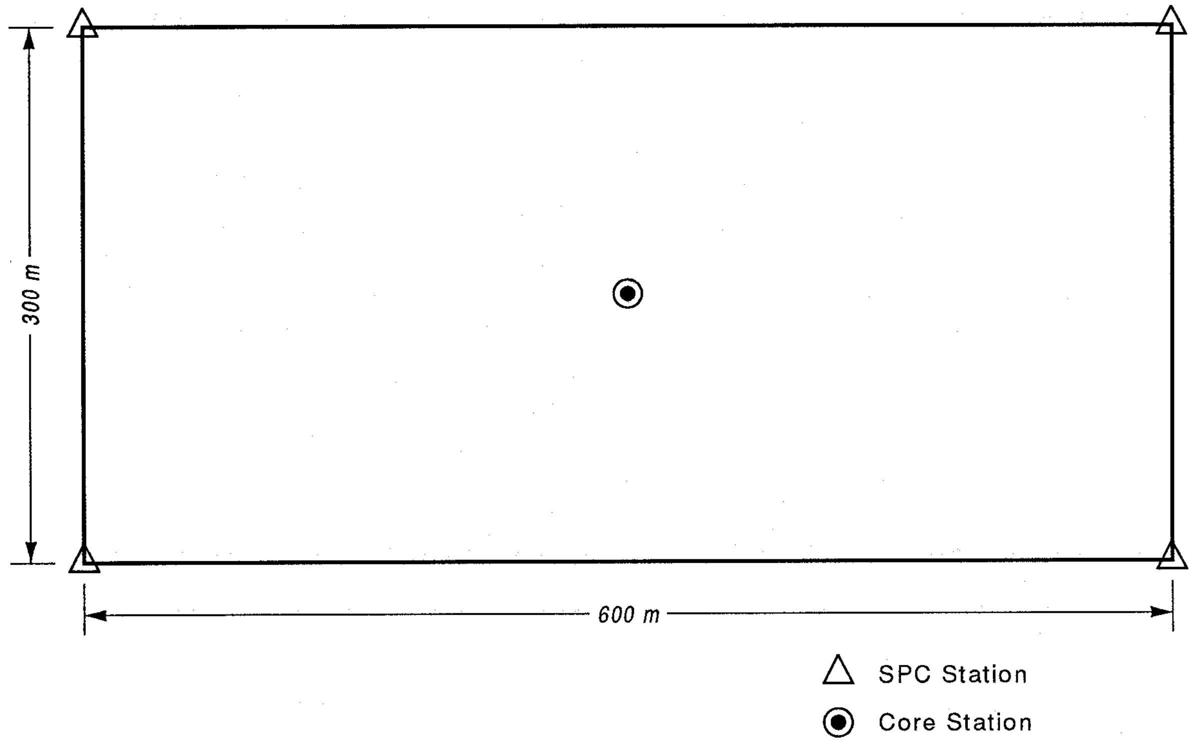


Figure 19. Illustration of typical placement grid showing monitoring station layout

Appendix A - Erosion Evaluation

The U.S. Army Engineer Waterways Experiment Station (WES) is currently evaluating options for in situ capping for Palos Verdes (PV) shelf contaminated sediments. This appendix describes one aspect of the study, an evaluation of erosion potential of cap material due to ambient and storm-generated currents and waves.

Erosion potential for in-place EA sediments under storm conditions was evaluated by Wiberg (1994). The model used parameterization derived from analysis of laboratory and field data from the site. Similar data were not available for potential cap material. The 1-dimensional model used in these simulations estimated the depth of erosion, depth of mixing, stratification of suspended sediments in the water column, and re-deposition of sediments eroded at the location. Because the model was 1-dimensional in the vertical direction, it did not actually estimate transport of sediments, only erosion and re-deposition at specified points at the 40 and 70 meter depth and did not include sediment transported from other segments of the site. The objective of the present simulations is to estimate erosion across the entire site as well as redeposition of all eroded sediments in the vicinity surrounding the site. Therefore a 1-dimensional vertical model was not considered appropriate for these simulations. The 2-dimensional, vertically integrated Long Term FATE (LTFATE) model (Scheffner, 1996; Scheffner et al., 1995) was considered more appropriate for estimating actual transport in the entire area.

The contaminated sediments lie on the shelf in water depths from 30 meters to 100+ meters. The deposit of contaminated sediments on the Palos Verdes shelf has been estimated to extend for approximately 11 km in the long-shore direction and approximately 2 km at the widest point in the cross-shore direction (Lee 1994). The LTFATE model has been modified and applied to the Palos Verdes shelf to assist in predicting the stability of various proposed capping materials and geometries.

LTFATE is a site-analysis program that uses coupled hydrodynamic, sediment transport, and bathymetry change sub-models to compute site stability over time as a function of local waves, currents, bathymetry, and sediment characteristics. LTFATE was developed to simulate the long-term fate and stability of dredged material placed in open water with an initial intended use for classifying existing or proposed disposal sites as dispersive or nondispersive. Site specific applications for predicting mound movement have also been completed and are described later. The model estimates the stability of a site for time periods ranging from days (for storm events) to years (for ambient conditions). If the site

is demonstrated to be dispersive, model output will provide an estimate of the temporal and spatial fate of the eroded cohesionless material. This determination is often difficult to quantify because the movement of sediment is a function of not only the local bathymetry and sediment characteristics, but also the time varying wave and current conditions. LTFATE overcomes these difficulties by using an information database to provide design wave and current time series boundary conditions that realistically represent conditions at the candidate disposal site.

The wave simulation methodology and the water surface elevation and current databases referenced in this report were developed through the Dredging Research Program (DRP) (Hales, 1995) at the U.S. Army Engineer Waterways Experiment Station (WES). The procedures for generating stochastic wave height, period, and direction time series are reported in Borgman and Scheffner (1991). The database of tidal elevations and currents for the Southern California Coast are described in Allard et al. (1996). Wave data necessary for these applications is derived from the Wave Information Study (WIS) hindcast for Southern California (Jensen et al., 1992). These sources are used to generate wave, stage height and current boundary condition data for use as input to LTFATE for evaluating mound stability. An outline of the derivation of specific LTFATE inputs is included later in this text.

LTFATE has the capability of simulating both non-cohesive and cohesive sediment transport. In addition, consolidation of cohesive sediments is accounted for to more accurately predict physical processes which occur at the site. Many sediment transport equations require near bottom velocities, but the methods incorporated in LTFATE were developed and work well using mean velocity of flow reflective of conditions outside the wave and current boundary layers. Unlike near-bottom velocities, these velocities are not significantly affected by bottom roughness. This is an advantage in regions where bottom roughness is unknown or continually changing. Following are sections describing the effects of waves on the sediment/water interface, non-cohesive sediment transport, cohesive sediment transport, and application of LTFATE to the Palos Verdes site.

Effect of Waves at Sediment/Water Interface

Most non-cohesive sediment transport equations are developed for a current-only environment. Areas of interest where LTFATE is applied normally include bottom stresses due to both currents and waves. Therefore the effects of waves must be included in estimating sediment transport. A modification of the transport equations proposed by Bijker (1971) is incorporated into LTFATE to reflect an increase in the transport rate if the ambient currents are accompanied by surface waves. The modification, in the form of an effective increase in the depth-averaged current velocity used to compute sediment transport, is based on equations reported by Swart (1976). This increased velocity can be thought of as the current velocity that would produce a bottom stress equivalent to the stress due

to the combined effects of ambient currents and waves. The effective increase in velocity for currents accompanied by waves V_{wc}, is written as a function of the current velocity V_c in the absence of waves as follows:

$$V_{wc} = V_c \left[1.0 + \frac{1}{2} \left(\xi \frac{\hat{u}_0}{V} \right)^2 \right]^{1/2} \tag{1}$$

where:

$$\xi = \hat{C} \left(\frac{f_w}{2g} \right)^{1/2} \tag{2}$$

$$\hat{C} = 18 \log \left(\frac{12d}{r} \right) \tag{3}$$

$$f_w = \exp \left[-5.977 + 5.213 \left(\frac{r}{a_0} \right)^{0.194} \right] \tag{4}$$

(if $f_w > 0.3$, $f_w = 0.3$)

$$\hat{u}_0 = \frac{Hgk}{2\sigma} \frac{1}{\cosh(kd)} = \frac{HgkT}{4\pi} \frac{1}{\cosh(kd)} \tag{5}$$

$$a_0 = \frac{Hgk}{2\sigma^2} \frac{1}{\cosh(kd)} = \frac{H}{2} \frac{1}{\sinh(kd)} \tag{6}$$

where $\hat{u}_0$ is the amplitude of the orbital velocity at the bed (Van De Graff and Van Overeem 1979), computed according to linear wave theory (Ippen 1966, p 28) and a_0 is defined as the orbital excursion (amplitude) at the bed (Swart 1976), computed from linear wave theory (Ippen 1966, p 29). In the above, the parameter f_w is defined as the bottom friction coefficient (Jonsson 1966). The parameter r is the hydraulic bed roughness and taken to be 0.197 ft (0.06 m), (Van De Graff and Van Overeem 1979). The terms H, k, σ, and T represent wave height (ft), wave number (ft^{-1}), angular frequency (sec^{-1}) and period (sec)

respectively. The terms d and g represent water depth (ft) and acceleration of gravity (ft sec^{-2}) respectively.

Non-Cohesive Sediment Transport Model Component

The equations reported by Ackers and White (1973) were selected as the basis for the non-cohesive sediment transport modeling component. These relationships predict sediment transport as a primary function of sediment grain size, depth, and depth averaged velocity (here the depth averaged velocity is assumed to be V_{wc}). The equations are applicable to well graded noncohesive sediment with a grain diameter in the range of 0.04 mm to 4.0 mm (White 1972).

The Ackers-White transport equations relate sediment transport to three dimensionless quantities. The first, a nondimensional grain size D_{gr}, is defined as a function of the ratio of the immersed particle weight to the viscous forces acting on the grain. The value is defined as:

$$D_{gr} = D \left[\frac{g(s-1)}{\nu^2} \right]^{1/3} \qquad \textbf{(7)}$$

where:

D = sediment diameter (i.e., D_{50}), ft
g = acceleration of gravity, ft/sec^2
s = sediment specific gravity
ν = fluid kinematic viscosity, ft^2/sec

The value of D_{gr} is used to categorize the sediment as coarse or transitional, with the following coefficients defined for the two sediment classifications:

a. Coarse sediments: $D_{gr} > 60$.
n = 0.0
m = 1.50
A = 0.17
C = 0.025

b. Transition sediments: $1.0 < D_{gr} \leq 60.0$

$$n = 1.00 - 0.56 \log(D_{gr}) \qquad \textbf{(8)}$$

$$m = \frac{9.66}{D_{gr}} + 1.34 \qquad \textbf{(9)}$$

$$A = \frac{0.23}{\sqrt{D_{gr}}} + 0.14 \qquad \textbf{(10)}$$

$$\log C = 2.86 \log D_{gr} - (\log D_{gr})^2 - 3.53 \qquad \textbf{(11)}$$

The second nondimensional parameter, F_{gr} , represents particle mobility defined as the ratio of shear forces to the immersed sediment weight. The general form of the relationship is

$$F_{gr} = \frac{v_*^n}{\sqrt{gD(s-1)}} \left[\frac{V_{wc}}{\sqrt{32} \log(10 \frac{d}{D})} \right]^{1-n} \qquad \textbf{(12)}$$

where V is the depth averaged velocity determined from the above described modification to the current velocity to account for the effect of waves (ft/sec), d is the mean depth of flow (ft), and v_* is the shear velocity (ft/sec) which can be defined from Chow (1959, p 204) as:

$$v_* = \frac{\sqrt{g} V_{wc}}{C_z} \qquad \textbf{(13)}$$

where C_z is the Chezy coefficient.

The third nondimensional parameter, G_{gr}, defines a sediment transport rate as a ratio of shear forces to the immersed weight multiplied by the efficiency of transport. The efficiency term is based on work needed to move the material per unit time and the total fluid power. The transport rate is written as

$$G_{gr} = \frac{Xd}{sD} \left(\frac{v_*}{V_{wc}} \right)^n \qquad \textbf{(14)}$$

where X is a nondimensional sediment transport function in the form of mass flux per unit mass flow rate. The sediment transport rate G_{gr} can be related to the mobility function F_{gr} through the following relationship:

$$G_{gr} = C\left(\frac{F_{gr}}{A} - 1.0\right)^{m} \qquad \textbf{(15)}$$

Equations 14 and 15 are used to solve for X as:

$$X = C\left(\frac{F_{gr}}{A} - 1.0\right)^{m}\frac{sD}{d}\left(\frac{V_{wc}}{v_{*}}\right)^{n} \qquad \textbf{(16)}$$

A dimensional sediment load transport rate Q_b, defined in cubic feet of sediment (solids) per second per unit width can be written as:

$$Q_b = XVd \qquad \textbf{(17)}$$

Therefore, the total sediment mixture transport, i.e., solids plus voids, is written as:

$$Q_b = \frac{Q_b}{(1-n)} \qquad \textbf{(18)}$$

where n is the porosity (ratio of void volume to total volume).

A dimensional sediment transport magnitude in volume (ft^3) of sediment mixture per second per unit width (ft) is finally written in the following form:

$$Q = C\left[\frac{F_{gr}}{A} - 1.0\right]^{m}\frac{sD}{(1-e)}\left(\frac{V_{wc}}{v_{*}}\right)^{n}V_c \qquad \textbf{(19)}$$

Equation 19 represents sediment transport as a primary function of depth, sediment grain size, and depth-averaged velocity.

LTFATE was applied to a site just south of Mobile Bay (Alabama) and successfully predicted the movement of the Sand Island disposal mound over a 30-month period from March 1987 through August 1989 (Scheffner 1996). Mound movement was tracked using six bathymetric surveys (Hands 1991). LTFATE predictions compared favorably to these bathymetry data, offering partial verification of the methods incorporated in the model.

Cohesive Sediment Transport Model Component

An improved cohesive sediment transport model has recently (1996) been incorporated into LTFATE. The model requires bottom shear stress as input. The total bottom shear stress due to currents and waves is determined using the combined current/wave 'perceived velocity', V_{wc} as described earlier in this section and bottom roughness parameters. The bottom shear stress equation, in *dynes/cm²*, is:

$$\tau = \rho_w g V_{wc}^{2} / C_z^{2}$$

where τ is the total bottom shear stress due to currents and waves, ρ_w is the density of water, g is the acceleration of gravity, V_{wc} is the perceived bottom velocity due to currents and waves, and C_z is the Chezy roughness coefficient. This method of calculating the shear stress compares favorably to more complex combined current/wave approaches like Christoffersen and Jonsson (1985), generally being within 20%. However, this method, like the others, is influenced by bottom roughness parameters. These parameters were not measured for the sediments of interest and the results may change significantly depending on their values. Bottom roughnesses for typical ocean sediments were used in lieu of actual data from the Palos Verdes shelf.

The factors influencing the resistance of a cohesive sediment bed to erosion may be best described by Ariathurai and Krone (1976) as: "(1) the types of clay minerals that constitute the bed; (2) structure of the bed (which in turn depends on the environment in which the aggregates that formed the bed were deposited), time, temperature, and the rate of gel formation; (3) the chemical composition of the pore and eroding fluids; (4) stress history, i.e., the maximum overburden pressure the bed had experienced and the time at various stress levels; and (5) organic matter and its state of oxidation." It is obvious from this description that the resistance of the bed to erosion will be different not only from site to site, but also potentially with depth at a given location. Therefore, erosion potential is usually considered a site-specific function of shear stress (and sometimes depth). Methods have been developed to determine erosion based on stresses, but these equations require parameters whose values are site specific. A commonly used method of relating erosion to shear stress has been incorporated into LTFATE. This method relates erosion as a function of shear stress to some exponential power. The equation for the erosion rate, ϵ, in $g/cm^2/sec$ is:

$$\epsilon = A_0 \left(\frac{\tau - \tau_{cr}}{\tau_r} \right)^m$$

where A_0 and m are site-specific parameters, τ is the shear stress due to currents and waves, τ_{cr} is the site-specific critical shear stress below which no erosion occurs (assumed to be 5 $dynes/cm^2$), and τ_r is a reference shear stress (assumed to be 1 $dyne/cm^2$). Most research on cohesive sediment erosion has been performed in laboratory settings at moderate shear stresses less than 20 $dynes/cm^2$ (Lavelle et al. 1984). The method incorporated into LTFATE was developed for moderate stresses. Data for high shear stresses are sparse and the experimental methods are still under development (McNeil et al. 1996). Despite this, a lot can be determined by using the moderate shear equations in high shear regions. It would appear from bathymetry measurements in high shear regions that the above equation can adequately simulate these conditions.

It should be noted that the values of the site-specific parameters used in these methods can vary significantly. Experimentally determined values of A_0 range over several orders of magnitude from $1x10^{-9}$ to $5x10^{-6}$ ($g/cm^2/sec$) and m ranges from 1 to 5 (Lavelle et al. 1984). The experimental range of exponent m values coupled with the equation for τ demonstrate that the relationship between velocity and erosion is highly nonlinear (τ is a function of V^2 and ϵ is a function of τ^m resulting in ϵ is a function of V^{2m}). Therefore, the rare storm events will produce most of the cohesive sediment erosion for a given year. This is well known to occur in many rivers, lakes and near shore environments. Some studies on San Francisco Bay sediments suggest that m ranges from 1-2 for these sediments, assuming they have had long compaction periods (Parthenaides 1965). The higher values of m are reserved for freshwater lake and river sediments. For application of LTFATE to the evaluation of erosion for capping options at the Palos Verdes shelf contaminated sediment site, values for A_0 and m were set at $7.6x10^{-8}$ $g/cm^2/sec$ and 2 respectively. These values are reasonable estimates for fairly well compacted cohesive sediments below the surficial layer. To determine values more accurate for the Palos Verdes site would require extensive testing of the proposed cap material to determine resuspension potential. The true coefficient and exponent values would in all probability not be constant, but would vary with depth and possibly from location to location. Without such data, the above mentioned values seem to be a reasonable first estimate for the upper one to two feet of cap material, fall within the expected experimental range, and are logical given what is known about density and grain size distribution of cohesive sediments currently at the site.

The critical shear stress value was set at 5 $dynes/cm^2$. This value is reasonable for well compacted sediments below the surficial layer (surficial layer defined as the top few centimeters of sediment). The surficial layer sediments are often recently deposited and are kept in a less dense, loose state by such factors as bioturbation and the agitation of current flow above the bed. These sediments have a critical shear stress less than 1 dyne/cm^2 and are easily resuspended. Therefore, to base erosion potential for all bottom sediments on the characteristics of the surficial layer would be a mistake. The surficial layer, usually only a few

centimeters thick, is ignored in the LTFATE model. Areas where mean conditions include relatively high shear stresses will not have a surficial layer.

Application of LTFATE Model

The LTFATE model is applied over a defined grid, but modeling the entire PV shelf and slope would be computationally impractical. Therefore, two representative model grids were defined over the area of highest contamination on the shelf for purposes of this modeling effort. The first model grid was defined as a 2 km x 2 km square located in water depths from 30 m to 100 m (see Figure A1). The second grid was defined as a 1 km x 4 km rectangle in the longshore direction in water depths from 45 m to 70 m (see Figure A2). A cap thickness of 1 meter was assumed for this evaluation for both grids, resulting in only a slight modification of existing water depths.

LTFATE is designed to model constant depth ambient conditions surrounding a dredged material mound, and the mound is assumed to be completely contained within the model boundaries (i.e., the model boundary depths are assumed to be constant). However, the Palos Verdes site is a large area with average slopes of 1 to 4 degrees on the shelf and 11 degrees on the continental slope. To model this situation, model geometries defining surrounding slopes were placed around the mound to bring the boundary water depths down to the deepest ambient depth (70 m for the 1x4 km mound and 100 m for the 2x2 km mound). These slopes should not affect the calculations of erosions for the defined mound because the mound itself is surrounded by a buffer region, 20 cells in width, which is comprised of the correct ambient depth conditions for that location. Based on these geometries, the mound as defined for this study consisted of a portion of the Palos Verdes shelf with the EA sediment deposit and overlying cap composing the surface of the mound. Figures A3a and A3b illustrate the LTFATE bottom geometry for the 1x4 km grid and Figures A4a and A4b illustrate the geometry for the 2x2 km grid. The 1x4 km cap simulation includes a total grid size of 258x115 cells, with each cell being 100 ft^2. The 2x2 km grid contains 246x176 100 ft^2 cells. Because of the large size of these grids, it was necessary to extend the maximum grid size of the original LTFATE model, which had a maximum capacity of a 51x51 grid. This grid size extension exceeded the limits for use of LTFATE on a standard 486 PC. Therefore the portion of LTFATE required to determine sediment transport (a program called PCDREDGE) was run on a UNIX workstation. The mound itself is comprised of only a fraction of the total grid because most of the grid is used either as the surrounding ambient ocean bottom, or as artificial cells to bring the boundary condition down to either 70 m or 100 m for the 1x4 km mound and 2x2 km mound respectively.

Sediment transport simulations were performed for the two model grids for each of three sediment types: 0.3mm sand, 0.1mm sand and fine grained cohesive silts and clays. First, full statistical year calculations were performed, then the five largest storms (as determined by maximum wave height) from the

20-year (1956-1975) WIS Southern California hindcast were simulated, and finally hypothetical events with maximum wave heights of 5.5 and 7.0 m respectively were simulated. Due to the protected location of the Palos Verdes shelf (many potentially large wave events are blocked by Catalina Island), the maximum wave heights for the 20-year hindcast are not nearly the magnitude of , for example, hurricane generated waves on the east coast. Maximum wave heights from the 20-year hindcast at station 15 (station closest to the mud dump site) are 3.5 m. The January 1988 storm was an episodic event that was not included in the WIS 20-year hindcast. The wave heights at station 15 reached a peak of 5.8 m during this storm. Due to this event, the hypothetical 5.5 and 7.0 m wave height events were modeled so that this report would include the effects of episodic events on the potential cap designs.

The wave/current/stage height database was developed as described by Scheffner (1996) except in this case for the West Coast. Only a brief outline will be given here. As previously mentioned, the database used to develop wave inputs for LTFATE is the WIS 20-year hindcast for Southern California. The wave data for the storm events are extracted directly from the database. The storm induced waves are measured at WIS station 15, which is close to the contaminated sediment site but is in deeper water. LTFATE accounts for the possible resulting change in wave height by shoaling the waves based on the difference in water depth between station 15 and the local water depth. The wave data for the statistical average year are estimated by first determining the intercorrelations between wave height, period and direction on a monthly basis for the entire 20-year hindcast and then building a statistically ‘average’ year based on this data. For details of this development, see Scheffner (1996). The wave heights for the one year simulation are presented in Figure A5.

Tidal and storm surge databases were generated using the ADCIRC finite element hydrodynamics model (Luettich et al., 1992). ADCIRC was designed to model large computational domains and has been calibrated and verified for the West Coast (Allard et al., 1996). The domain used to develop databases for the Palos Verdes site is presented in Figure A6 and includes a portion of the Pacific Ocean from Punta Pequena, Mexico to San Francisco Bay and extends to 126.6 degrees west. The original grid used by Allard et al. (1996) was modified for this application to include a finer grid near the Palos Verdes site. Details of this finer grid, including the location of the contaminated sediment site, are presented in Figure A6. For the storm events, wind data were used as input to ADCIRC to develop surge elevation and current velocities for each of the five storms. LTFATE requires local tidal constituent data for the one-year simulations. The Le Provost database was used to develop tidal constituent boundary conditions used as input to ADCIRC, which then uses a harmonic analysis package to develop local tidal constituents, in this case for the Palos Verdes shelf at 118.3167 E longitude and 33.6917 N Latitude. The tidal constituent parameters used to develop the statistical year, as derived from ADCIRC, were somewhat different from the constituent parameters measured by the USGS and applied to the Palos

Verdes shelf contaminated sediment site by Moffatt and Nichol Engineers (Headland et al., 1995). LTFATE statistical average year simulations were performed using tidal constituents from both ADCIRC and USGS data. Therefore for the statistical average year, there were two tidal constituents modeled, besides the two geometries and three sediment types.

LTFATE Model Results

The results of the evaluation are summarized in Tables A1 through A3. The magnitude of erosion was strongly a function of the water depth. The maximum erosion, average erosion, and erosion at the 40 m and 100 m contours are shown in the tables. The 30 to 40 m water depth is the shallowest depth at which the effluent-affected sediment is evident based on USGS data. The 70 to 100 meter water depth is that for the “shelf break”, the point at which the bottom slopes dramatically increase. For this evaluation, no additional cap thickness to account for erosion processes would be deemed necessary in the context of cap design for erosion values of 0.1 foot or less. For all modeled conditions, the maximum erosion was evident at the edge or corners of the cap at the shallowest water depth (either 30 or 45 m, depending on the grid), and the average erosion was significantly lower than the maximum. Also, no erosion greater that 0.1 foot was indicated for any modeled condition at water depths exceeding 45 m.

Results for ambient currents are summarized in Table A1. The statistical average year simulations indicated essentially no erosion during an ‘average’ year, for the entire 1x4 km grid (45-70 m water depths). This includes all types of sediments and both the WIS and USGS tidal constituents. For the 2x2 km grid in 30-100 m water depths, essentially no erosion occurred for the 0.1 and 0.3 mm sands for either tidal constituent inputs. However, erosion was indicated for the cohesive sediment cap although the depths of erosion are not significant. Table A1 presents the results of cohesive sediment cap erosion for the 2x2 km cap for both the WIS and USGS tidal constituent inputs. It can be seen that the erosion for the 40 m depth is essentially zero. The maximum erosion for cohesive material for the USGS tidal constituents is 0.3 ft, while for the WIS data it is 0.2 ft.

Results for hindcast storm events are summarized in Table A3. Most of the five storm events modeled indicated that a cap consisting of any of the three types of material will partially erode for the 2x2 km grid in 30-100 m water depths. Conversely, none of the events chosen from the 20-year hindcast would erode any material for the 1x4 km grid located in 45-70 m water depths. It is interesting to note that the storm that produced the most erosion of cohesive sediments did not also produce the most erosion of sands. This is due to the very different nature of sand and cohesive sediment erosion. While cohesive sediments are resuspended into the water column and carried away from the cap site, sands tend to move as bedload from one cell to the next and many parts of the cap experience net deposition of sediments. Net deposition of cohesive sediment rarely occurs on a protruding cap or mound. Therefore, the same storm conditions may

produce very different results for cohesive sediments and sands. It is clear from Table A2 that although the deepest erosion was for the 0.1 mm sands (up to 1.5 ft), these deep packets of erosion were isolated (usually at the edge of the cap mound at the shallowest water depth of 30 m) and the average erosion was significantly lower (0.35 ft). Consistently, the greatest volumes of erosion (due to their dispersive nature) are the cohesive sediments, which also experienced the highest average erosion and the highest percent of surface area experiencing net erosion. It should be emphasized that no erosion greater than 0.1 feet was evident for any of the hindcast events for either grid for any of the three cap materials at water depths greater than 40 m.

The hypothetical episodic events were established by altering storm inputs for the 3/74 storm to include 18 hours of 5.5 m or 7.0 m waves (ramped to these peaks at a rate of 0.5 m per 3 hours). The results of these computations for both the 2x2 km and 1x4 km configurations are presented in Table A2. These results indicate that, as would be expected under high wave conditions, there is significant erosion for both the cohesive sediment and 0.1 mm sand on the 2x2 km grid in shallow water depths, but clearly the cohesive sediments suffered more significant erosion. The 0.3 mm sand demonstrated more resistance to erosion, even at these high shear stresses, experiencing a maximum of 0.6 feet erosion, an average of less than 0.2 ft erosion (over areas experiencing net erosion), and less than 10% of the total erosion compared to the cohesive sediment. It is interesting to note that even under the severe 7.0m conditions (higher than any measured waves at this site) no significant cap erosion occurs at water depths exceeding 40 meters for the 0.1 mm or 0.3 mm sands. It should be reiterated that 7.0 m waves have never been measured near this site. The highest measured waves are the 5.8 m waves of the January 1988 storm. The model predicts no sand erosion for either 5.5 m or 7.0 m waves at the deeper water 1x4 km grid. Only minor erosion, less than 0.3 ft, is expected for the cohesive sediments at the 1x4 km grid.

One possible source of cap sediments is the Queen's Gate entrance to the Port of Long Beach, and this material is considered representative of the materials most likely available for use as cap materials. Particle size analysis on 45 core samples extracted from the proposed navigation channel site indicates that, for most cores, between 30 and 80 percent of the material is classified as silt or clay. The remainder of the sediments is predominately fine grain sands (approximately 0.1-0.2 mm diameter) (Sea Surveyor, Inc., 1994). Classifications were mostly silty sand (more than 50% of material is larger than No. 200 sieve size, but containing an appreciable amount of fine grain material), sandy silt (more than 50% of material is smaller than No. 200 sieve size, but containing appreciable amount of fine sand), or a type of clay or silt.

The cap material that settles to the bottom will contain a higher percent coarse material as compared to the material prior to dredging and placement because of dispersion of the fine sediments. But, as previously indicated, erosion potential is site specific. Experiments on specific cap materials, considering the

effects of dispersion of the finer fraction, would provide the information necessary to determine more accurate erosion potential for the proposed cap.

In summary, the magnitude of erosion was strongly a function of the water depth. The maximum erosion was evident at the edge or corners of the cap model grid at the shallowest water depths. No erosion greater than 0.1 feet was evident for ambient current conditions or for any of the hindcast storm events for sand or clay/silt cap materials at water depths greater than 40 m. For severe (7.0 m) hypothetical waves, no significant cap erosion occurs at water depths exceeding 40 meters for the 0.1 mm or 0.3 mm sands, but erosion occurs for clay/silt material caps. Available capping materials are most likely to be a mixture of sands and fine materials. Based on these results, no additional thickness of cap material is warranted for purposes of erosion resistance for placement of caps at water depths exceeding about 40 m.

References

Ackers, P., and White, W.R. (1973). “Sediment transport: New approach and analysis,” J. Hydraul. Div. Am. Soc. Civ. Eng., 99(HY11), pp 2041-2060.

Allard, R., Farrar, P. Mark, D. Martin, J. Shapiro, B. Lowe, S. and Ko, D.S. (1996). “Creating a 4-D integrated scenario near Camp Pendelton CA,” *Proceedings of the Conference on Coastal Oceanic and Atmospheric Prediction*, Am. Meteorological Soc., Boston, MA.

Ariathurai, R., and Krone, R.B. (1976). “Finite element model for cohesive sediment transport,” J. Hydraul. Div. Am. Soc. Civ. Eng., 102(HY3), pp 323-338.

Bijker, E. (1971). “Longshore transport computations,” J. Waterways, Harbors and Coastal Eng. Div. Am. Soc. Civ. Eng., 97(WW4), pp 687-701.

Borgman, L.E., and Scheffner, N.W. (1991). “The simulation of time sequences of wave height, period and direction,” Technical Report DRP-91-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Christoffersen, J.B., and Jonsson, (1985). “I.G. bed friction and dissipation in a combined current and wave motion,” Ocean Engng., 12(5), pp 387-423.

Chow, V.T. (1959). “Open channel hydraulics,” McGraw-Hill Book Company, New York, NY.

Hands, E.B. (1991). “Unprecedented Migration of a submerged mound off the Alabama Coast,” *Proceedings Coastal Sediments 91*, Seattle, WA.

Hales, L. (1995). “Accomplishments of the Corps of Engineers dredging research program,” J. Coastal Res., 11(1), pp 68-88.

Headland, R.E., Lesnik, J.R. McNeilan, T.W. and Hooper, J.R. (1995). “Feasibility study of sediment restoration alternatives for the southern california natural resource damage assessment Appendix G: Hydrodynamics and geotechnical assessment of the in situ capping alternative,” Moffatt and Nichol Engineers, Baltimore, MD.

Ippen, A.T., ed., (1966). “Estuary and coastline hydrodynamics,” McGraw-Hill Book Co., Inc, New York, NY.

Jensen, R.E., Hubertz, J.M. Thompson, E.F. Reinhard, R.D. Bishop, B.J. Brandon, W.A. Payne, J.B. Brooks, R.M. and McAneny, D.S. (1992). “Southern California hindcast wave information,” WIS Report 20, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Jonsson, I.G.,(1966). “Wave boundary layers and friction factors,” *Proceedings Coastal Engineering Conference*, 10th, Tokyo, Japan.

Lavelle, J.W., Mofjeld, H.O. and Baker, E.T. (1984). “An in situ erosion rate for a fine-grained marine sediment,” J. Geophys. Res., 89(C4), pp 6543-6552.

Lee, H.J. (1994). "The distribution and character of contaminated effluent-affected sediment, Palos Verdes Margin, Southern California," Expert Report.

Luettich, R.A., Westerlink, J.J. and Scheffner, N.W. (1992). “ADCIRC: an advanced three-dimensional circulation model for shelves, coasts, and estuaries, Report 1: theory and methodology of ADCIRC-2DDI and ADCIRC-3DL,” Technical Report DRP-92-6, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

McNeil, J., Taylor, C. and Lick, W. (1996). “Measurements of the Erosion of undisturbed bottom sediments with depth,” accepted for publication to J. Hydraul. Eng.

Parthenaides, E., (1965). “Erosion and deposition of cohesive soils,” J. Hydraul. Div. Am Soc. Civ. Eng., 91(HY1), pp 105-138.

Sea Surveyor, Inc. (1994). “Queen’s Gate Dredging geotechnical and chemical investigation,” Report prepared for The Port of Long Beach by Sea Surveyors Inc., Benicia, CA.

Scheffner, N.W., Mark, D.J. Blain, C.A. Westerlink, J.J. and Luettich, R.A. (1992). "ADCIRC: an advanced three-dimensional circulation model for shelves, coasts, and estuaries report 5: a tropical storm data base for the East and Gulf of Mexico Coasts of the United States," Technical Report DRP-92-6, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Scheffner, N.W. (1996)."Systematic analysis of long-term fate of disposed dredged material," J. Waterways, Harbors and Coastal Eng. Div. Am. Soc. Civ. Eng., 122(3).

Swart, D.H. (1976). "Predictive equations regarding coastal transports, Coastal Engineering," Volume 2.

Van De Graff, J., and Van Overeem, J. (1979). "Evaluation of sediment transport formulae in coastal engineering practice," Coast. Engrg., Amsterdam, 3, 1-32,

White, W.R. (1972). "Sediment transport in channels: a general function," INT 104, Wallingford Hydraulics Research Station, Wallingford, UK.

Table A1
Erosion results for ambient current conditions (2x2 km cap)

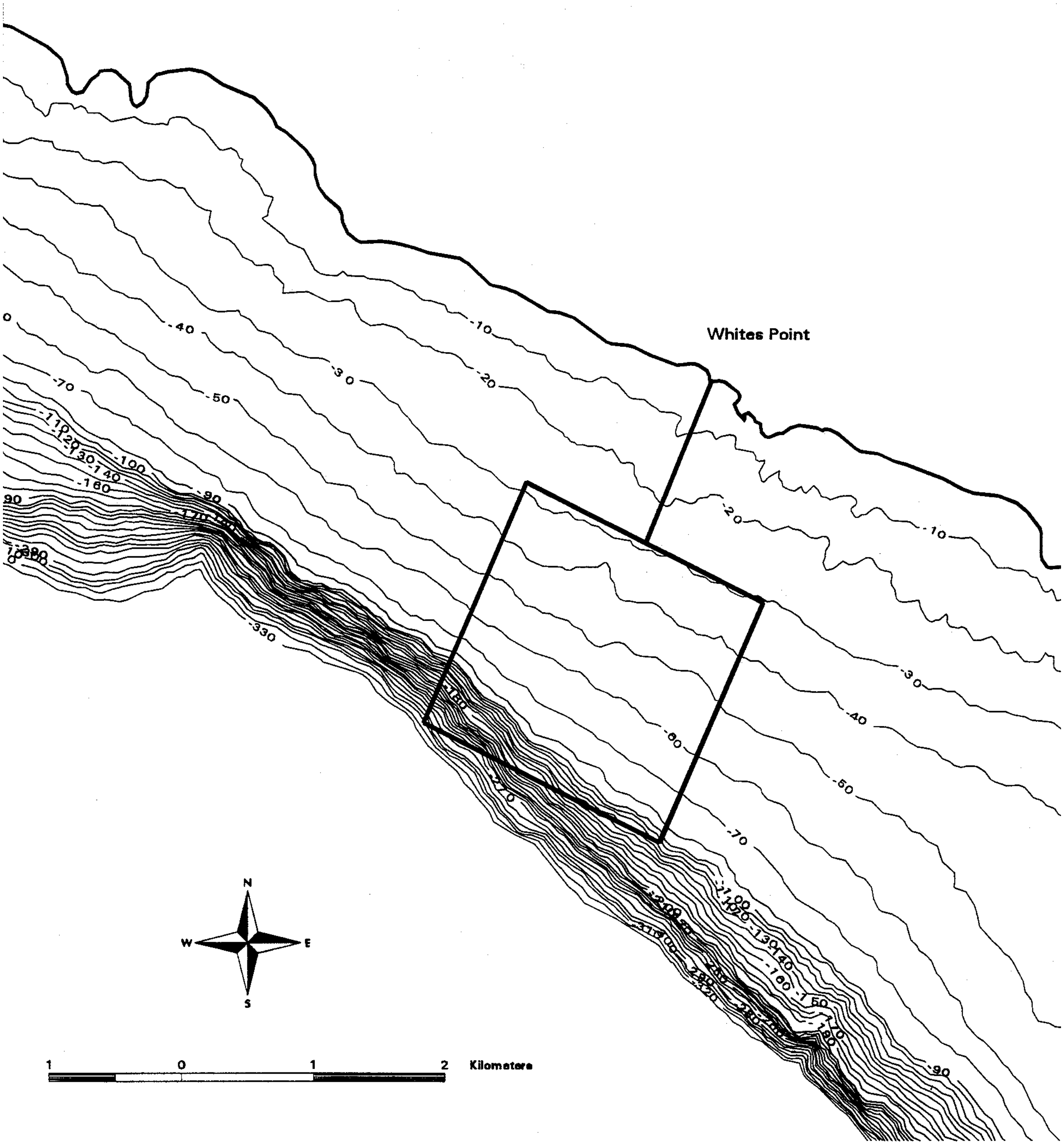
Tidal Constituent	Sediment Type	Maximum Erosion (ft)	Average Erosion (ft)	Erosion at 40 m (ft)	Erosion at 100 m (ft)
WIS	Cohesive	0.2	.150	0.	0.
USGS	Cohesive	0.3	.200	0.	0.

Table A2
Erosion results for hypothetical storm events

Maximum Wave Height (m)/Geometry	Sediment Type	Maximum Erosion (ft)	Average Erosion (ft)	Erosion at 40 m Depth (ft)	Erosion at 100 m Depth (ft)
5.5/ 2x2 km	0.1mm	1.20	0.33	0.00	0.00
	0.3mm	0.40	0.14	0.00	0.00
	Cohesive	1.20	0.60	0.30	0.00
7.0/ 2x2 km	0.1mm	1.50	0.37	0.10	0.00
	0.3mm	0.60	0.18	0.10	0.00
	Cohesive	2.00	0.86	0.60	0.00
5.5/ 1x4 km	Cohesive	0.10	0.10	---	0.00
7.0/ 1x4 km	Cohesive	0.30	0.20	---	0.00

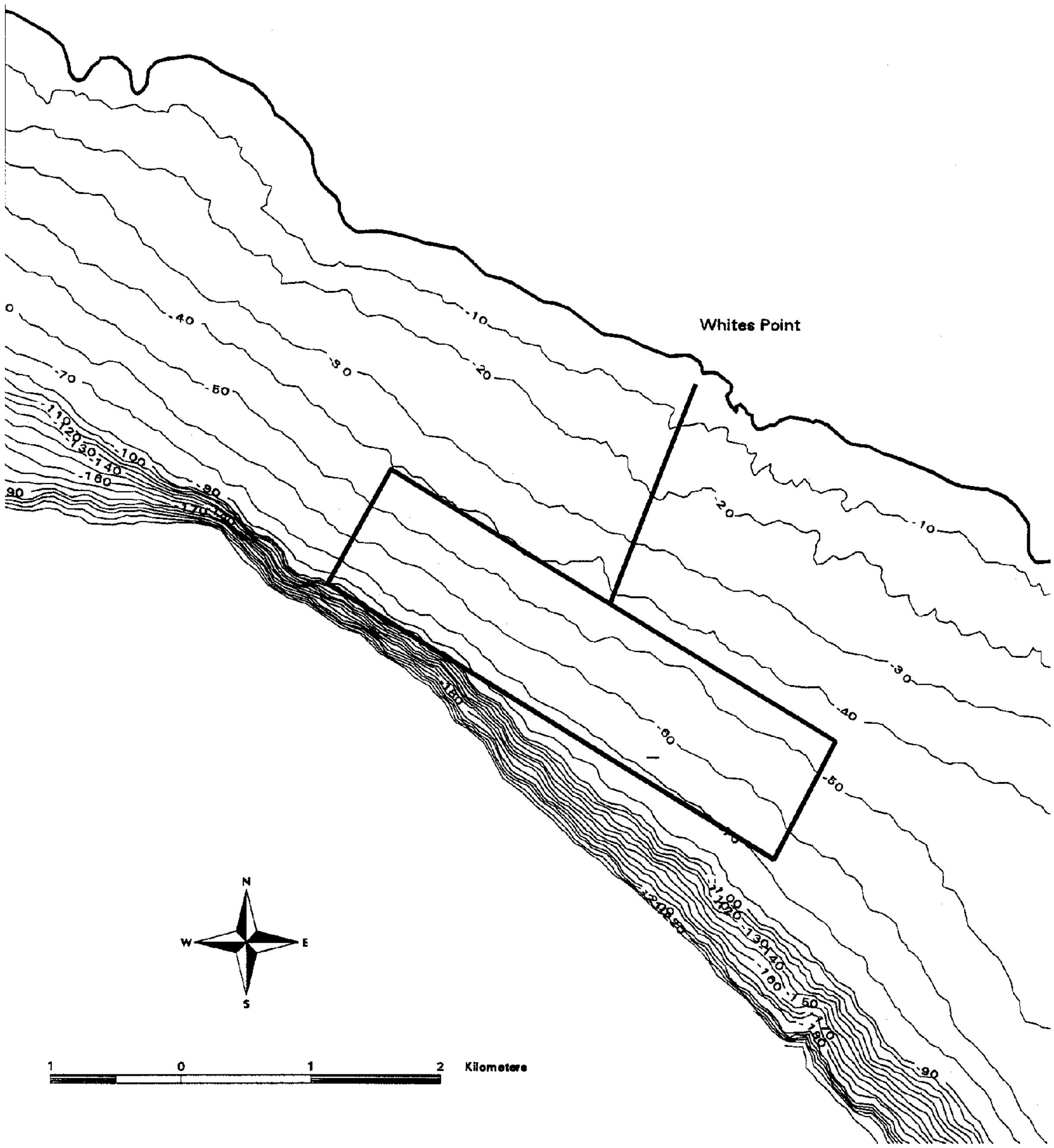
Table A3
Erosion results for storm events

Date (Mo/yr)	Sediment Type	Maximum Erosion (ft)	Average Erosion (ft)	Erosion at 40 m Depth (ft)	Erosion at 100 m Depth (ft)
12/64	0.1mm	0.30	0.14	0.00	0.0
	0.3mm	0.20	0.10	0.00	0.0
	Cohesive	0.50	0.30	0.10	0.0
12/69	0.1mm	0.10	0.10	0.00	0.0
	0.3mm	0.00		0.00	0.0
	Cohesive	0.70	0.40	0.10	0.0
1/70	0.1mm	0.10	0.10	0.00	0.0
	0.3mm	0.00		0.00	0.0
	Cohesive	0.30	0.22	0.10	0.0
2/60	0.1mm	1.50	0.36	0.10	0.0
	0.3mm	0.20	0.11	0.00	0.0
	Cohesive	0.50	0.31	0.10	0.0
3/74	0.1mm	1.00	0.30	0.00	0.0
	0.3mm	0.30	0.13	0.00	0.0
	Cohesive	0.70	0.41	0.10	0.0



2 x 2 KM area centered at White Point outfall

Figure A1. PV Shelf with 2x2 km area for potential placement of in-situ cap



1 x 4 KM area centered at White Point outfall

Figure A2. PV Shelf with 1x4 km area for potential placement of in situ cap

Figure A3a. Crossshore cross-section of LTFATE grid for 1x4 km cap

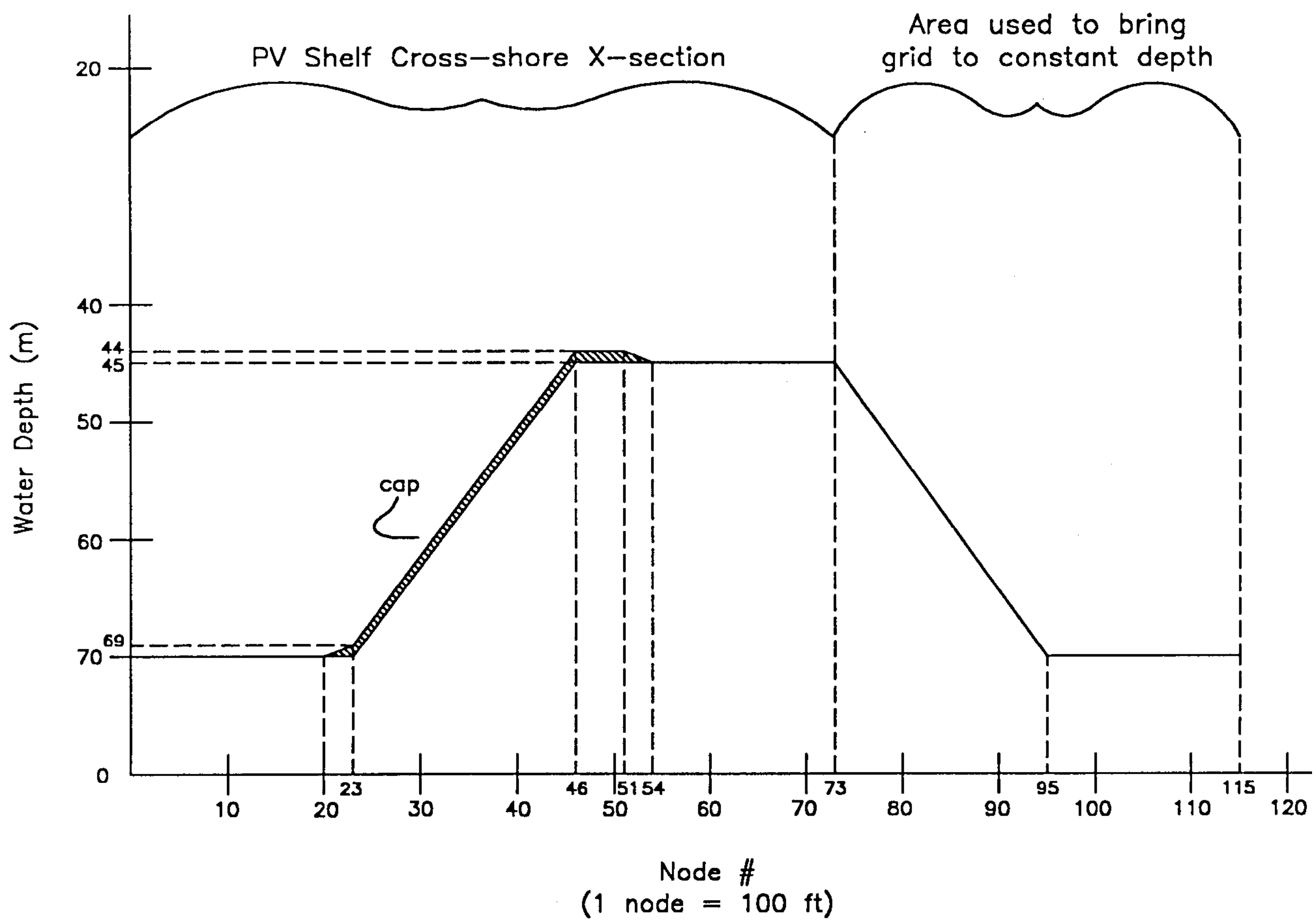


Figure A3b. Longshore cross-section of LTFATE grid for 1x4 km cap at 45 m ambient water depth

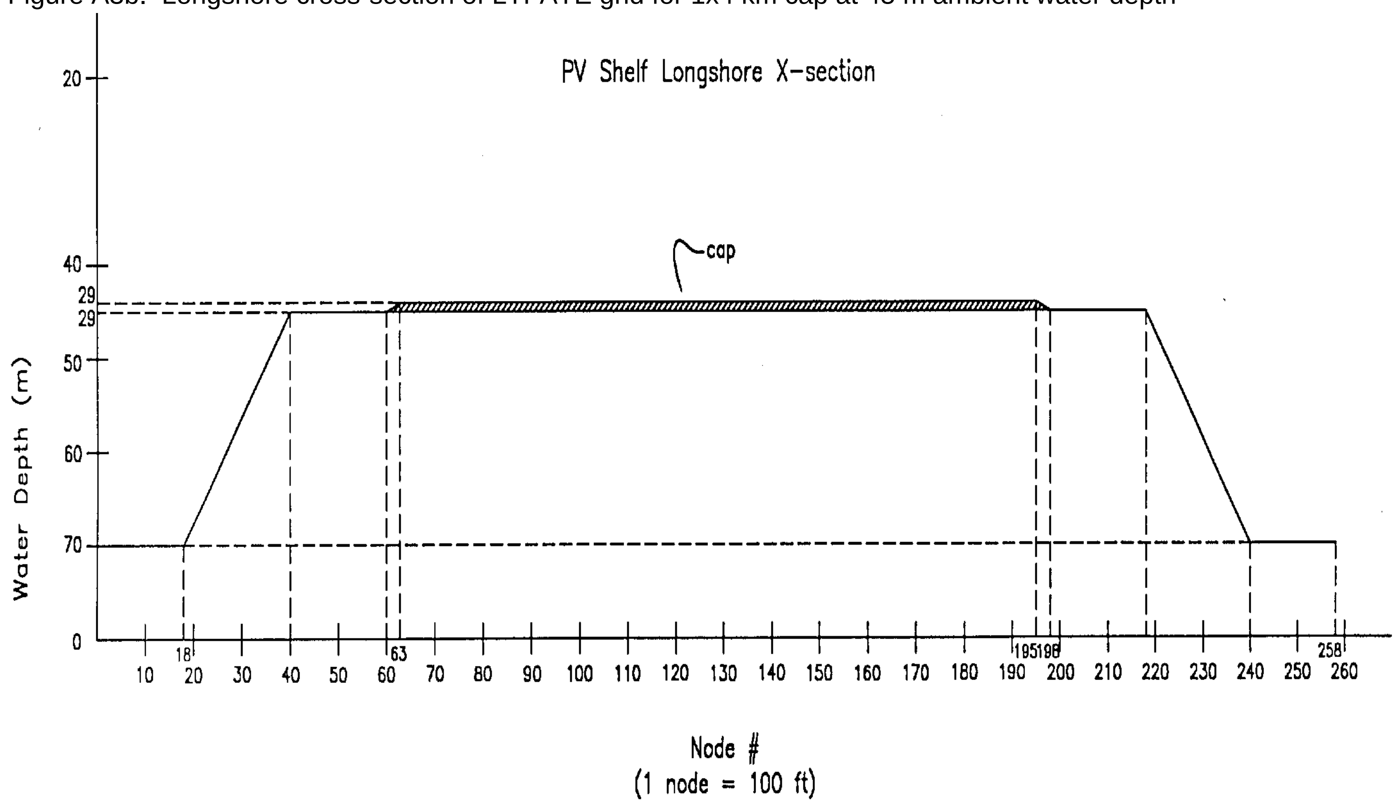


Figure A4a. Crossshore cross-section of LTFATE grid for 2x2 km cap

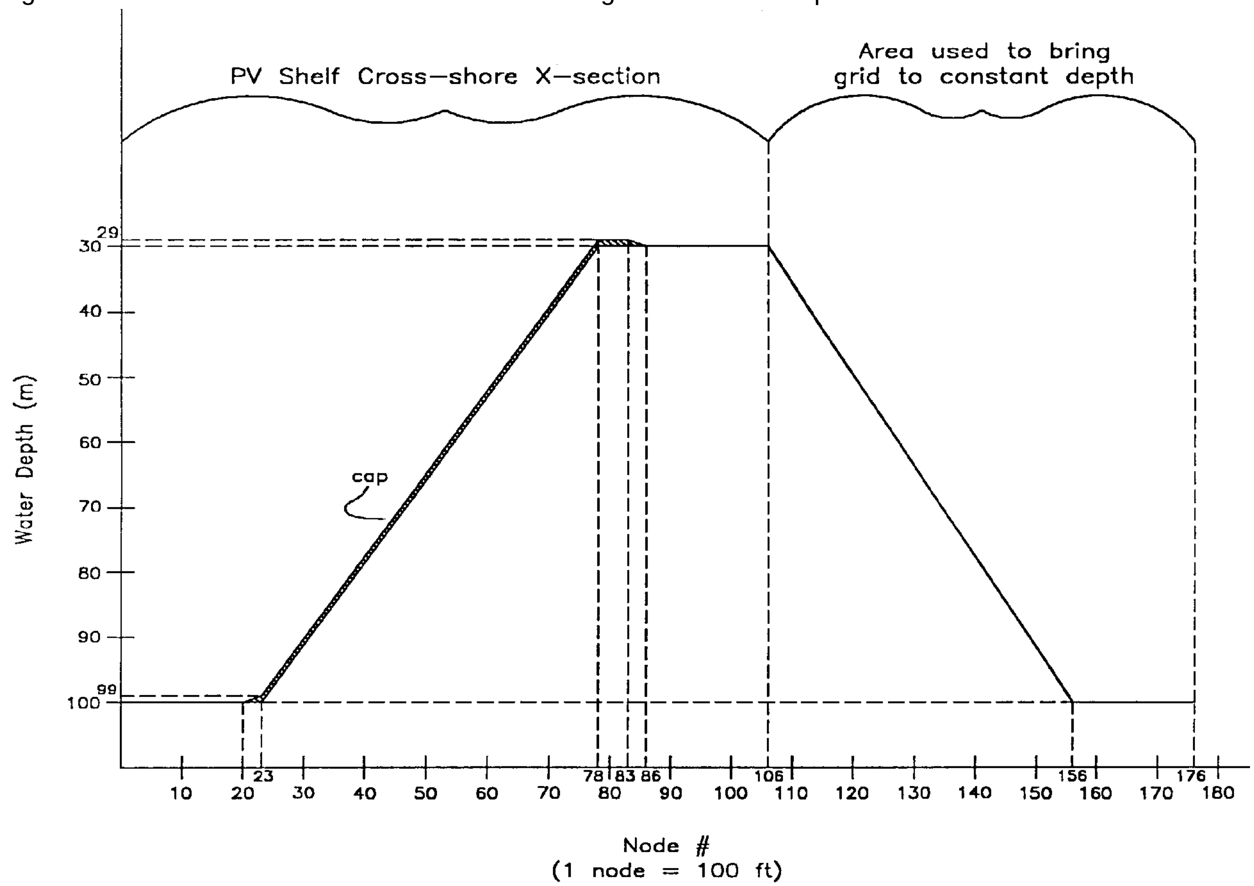
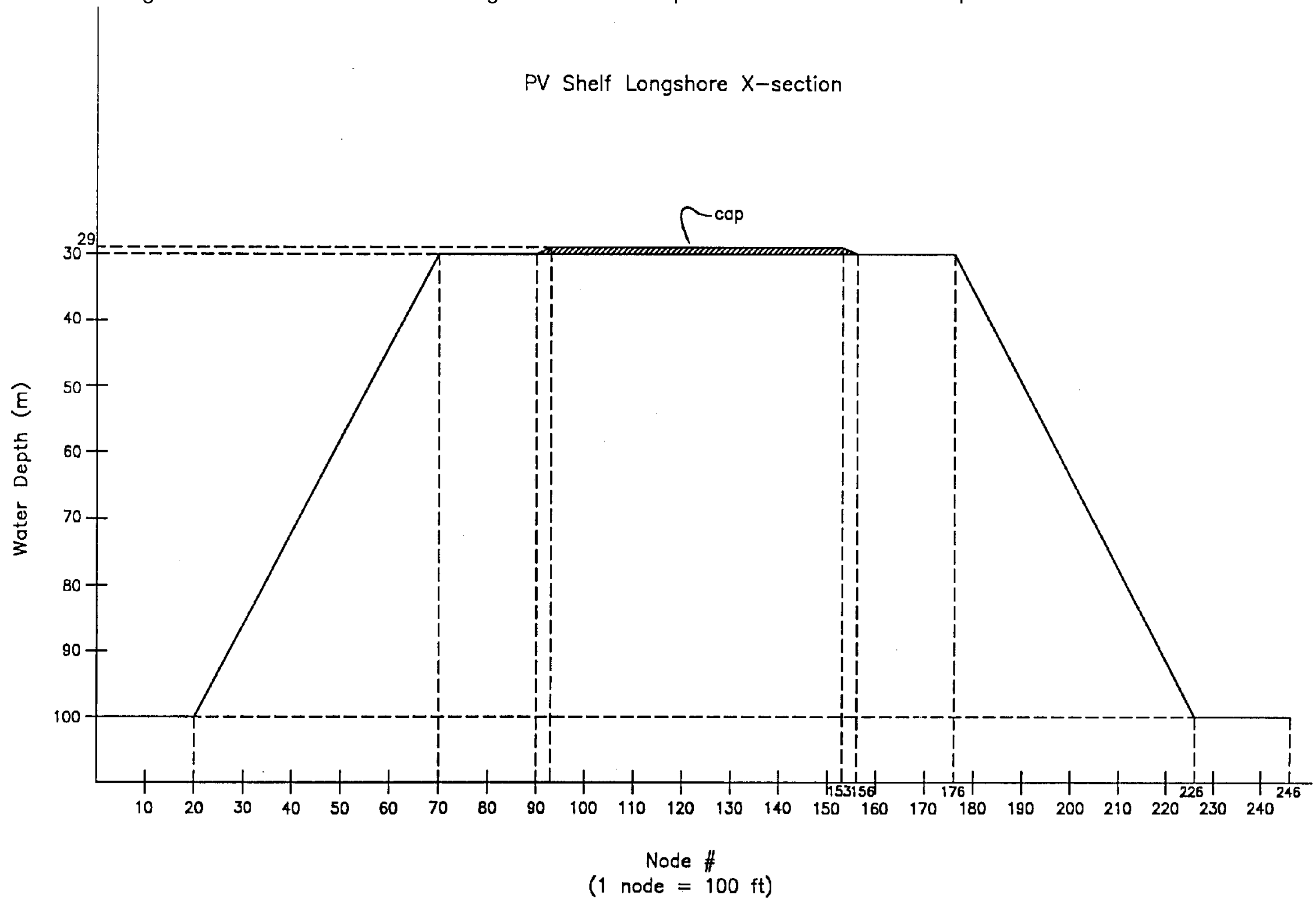


Figure A4b. Longshore cross-section of LTFATE grid for 2x2 km cap at 30 m ambient water depth



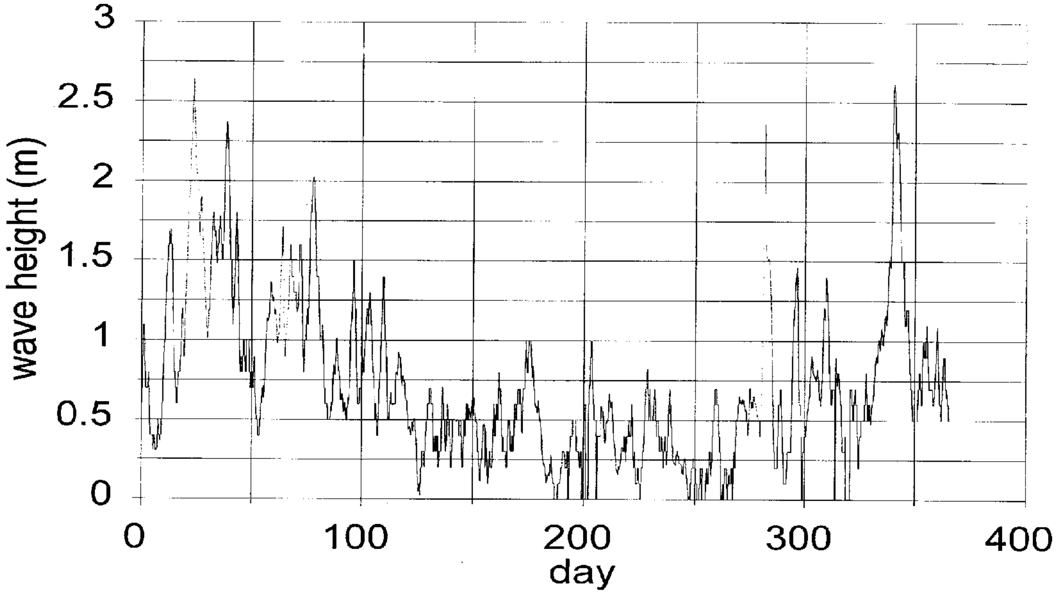


Figure A5. Wave heights for a statistically average year

Figure A6. ADCRIC grid for southern California

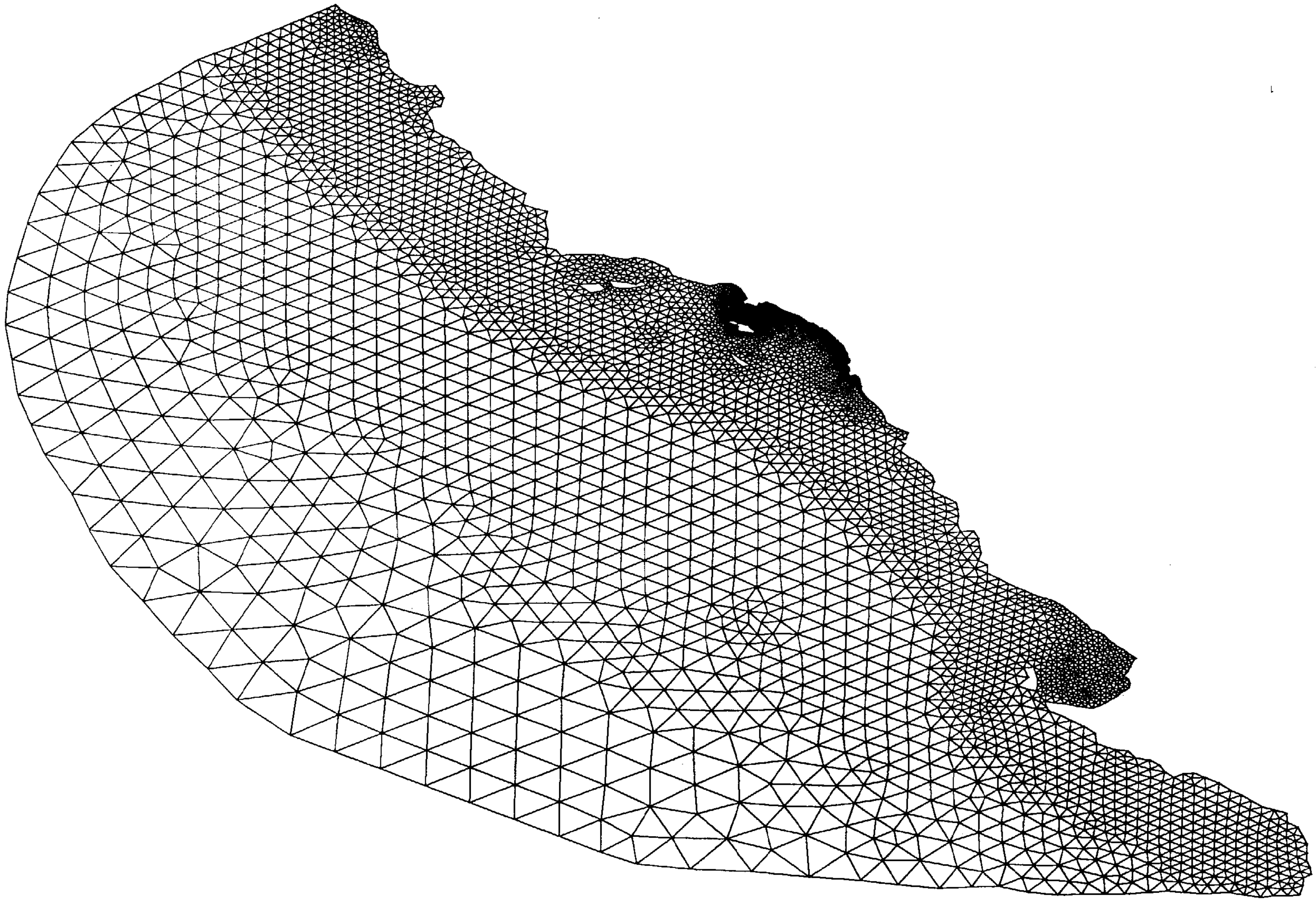
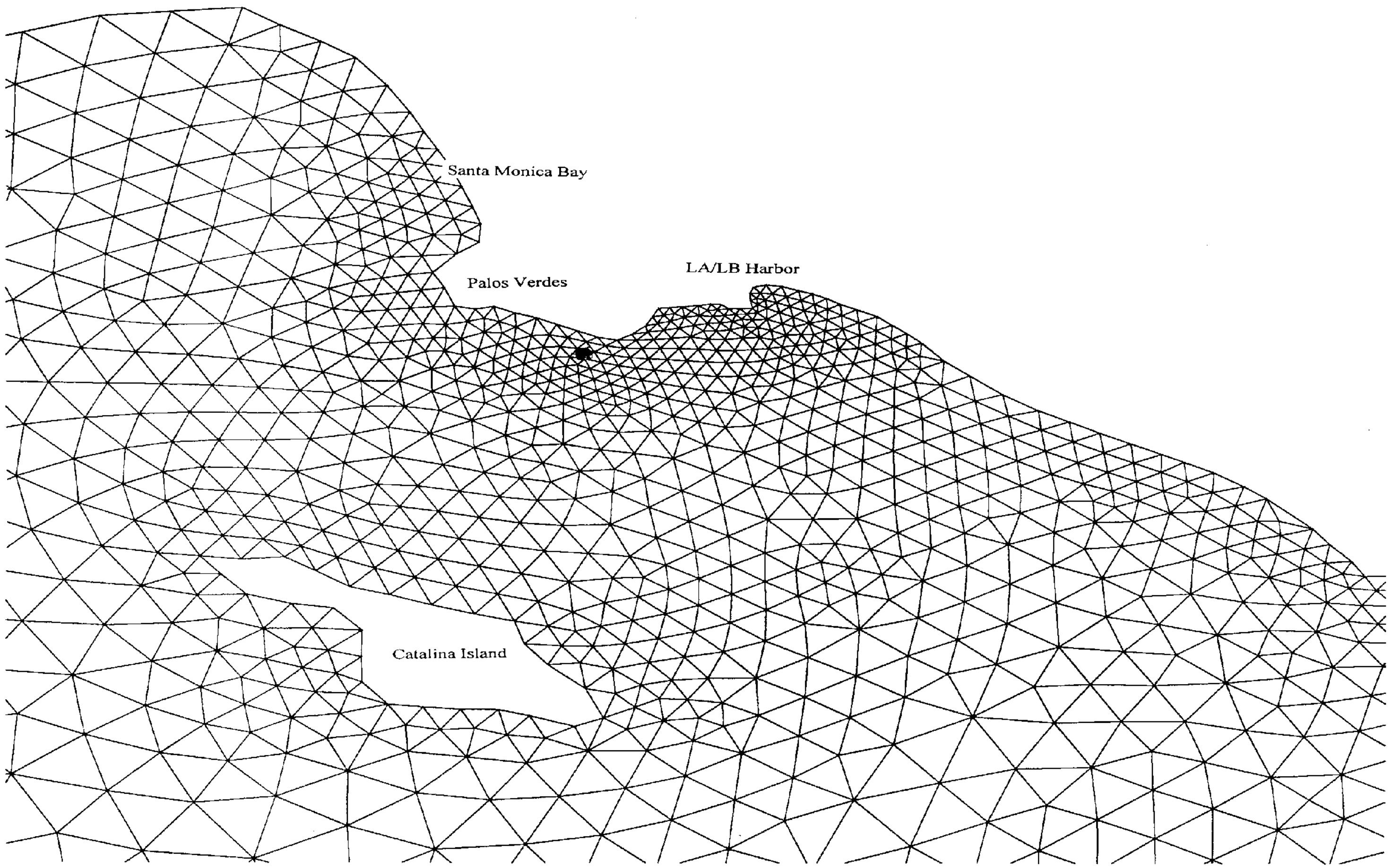


Figure A7. Detail of ADCIRC grid near Palos Verdes (contaminated sediment site is indicated by large dark circle)



Appendix B - Seismic Evaluation

Introduction

The U.S. Army Engineer Waterways Experiment Station (WES) is currently evaluating options for in situ capping for Palos Verdes (PV) shelf contaminated sediments. This appendix describes one aspect of the study, an evaluation of seismic stability.

The primary issue addressed in this evaluation is: Would the presence of this capping layer render the deposits unstable against sliding during moderate earthquakes, exposing materials with high concentrations of DDT at the ocean floor? A number of specific questions are addressed:

1. Are the existing surface sediments susceptible to flow failure?
2. Would the construction of a cap render the contaminated deposit susceptible to flow failure?
3. Would the cap fail and drag existing cover sediments off, exposing contaminated soils?
4. Would the cap and/or sediment "liquefy", and what deformations will occur?
5. What are the weaknesses in the data and analyses so far, and what can be done to improve on them?

Susceptibility of Existing Sediments to Flow Failure

The existing sediments will be susceptible to flow failure if the initial static shear stress (t_o) induced by the slope of the ocean floor exceeds the steady-state shear strength (S_{us}) of the sediments (Castro 1995). This is demonstrated conceptually in Figure B1. If a soil has t_o greater than S_{us} and it is strained beyond a threshold level (e_t) either by monotonic loading (Figure B1a) or cyclic loading (Figure B1b), the soil will continue to deform to very large levels. Conversely, if a soil has t_o less than S_{us} , then there is a reserve strength available even after e_t has been exceeded, and the soil will not continue to deform unless additional shear stress is applied either monotonically (Figure B1c) or cyclically (Figure B1d). If the cyclic shear stresses exceed (S_{us}), but t_o is less than S_{us} , then deformations may accrue during cycling, but the material will restabilize after cyclic loading has stopped with limited levels of deformation. This type of restabilizing behavior for loose, liquefiable materials under gentle sloping ground stress conditions has been observed in laboratory tests (Taboada and Dobry 1992,

Arulmoli et al. 1992), in centrifuge tests (Dobry, Taboada and Liu 1995), in shake-table tests (Sasaki et al. 1991), and in field observations of earthquake-induced lateral spreading (Baziar and Dobry 1995).

The S_{us} of a soil is a function of density, expressed either as void ratio (e) or water content (w) for saturated soils. The steady-state behavior of a soil in drained (S) and undrained (R) shear is summarized in Figure B2. At a given effective normal stress in drained shear (Figures B2a and B2c), a loose sample (S1) will contract and a dense sample (S2) will dilate, but both samples will seek the limiting value of void ratio for that confining stress as defined by the steady-state line for that material (Figure B2d). The shear tests give the value of S_{us} to associate with a given water content (Figures B2b and B2d). This steady-state strength model, developed mainly for sands and silty sands is similar to models developed for cohesive soils that relate confining stress, water content, and undrained shear strength (for example, see Lambe and Whitman 1969).

The field and laboratory investigations reported by Lee and McArthur (1995) provide data from which the steady-state strengths for the Palos Verdes sediments can be estimated. The triaxial test results indicate steady-state strengths of approximately $S_{us} = 0.3\ s_{vo}'$ for confining stresses ranging from 5.7 to 101.3 kPa and water contents ranging from 38.8 to 95.2 percent. The laboratory vane shear tests from Lee and McArthur (1995) indicate residual strengths of about 0.3 to 0.5 kPa in these sediments at water contents up to about 200 percent. These data are plotted in Figure B3.

The initial static shear stress t_o is computed from the slope angle a^o and the vertical effective stress s_{vo}':

$$t_o = s_{vo}' \sin a^o \qquad (1)$$

The factor of safety against flow failure is the ratio of the residual or steady-state strength S_{us} to the static driving stress t_o . The laboratory vane residual strength data result in safety factors against flow failure in the existing sediment of about 10 on the shelf where slope angles range from about 1 to 5 degrees. On the shelf break, where the slope angles may range from 13 to 18 degrees, the safety factor against flow failure is near one. Calculations are shown in Addendum A, Table A1.

Effect of a Cap on Flow Failure Susceptibility

Addition of a cap will increase the static driving shear stress in the contaminated sediment since the vertical effective stress is increased (Equation 1). Unless there is a corresponding increase in residual strength, this added driving stress will reduce the safety factor against flow failure. The addition of a 1 to 3 ft cap will generally not overcome the maximum past pressures estimated for the

sediments by Lee and McArthur (1995), consequently there will be little volume change and the steady-state strength will not increase significantly. The Lee and McArthur (1995) data indicate that safety factors are about 1.5 or greater for a cap of 2-ft and slopes of 5 degrees or less, and placement of a cap of 1-ft or greater on the shelf break would reduce safety factors against flow failure to less than 0.5 on these steeper slopes. Calculations are shown in Addendum A, Table A1.

Stability of the Cap Against Flow Failure

Placement of the cap materials by pluviation through water is expected to result in a silty, sandy deposit with a relative density D_R of about 55 percent, based on field and laboratory observations of hydraulically placed materials (Seed, Idriss, Makdisi 1973). Relative density is defined as:

$$D_R = [(e_{max} - e) / (e_{max} - e_{min})] \times 100\% \qquad (2)$$

where e_{max} is the void ratio of the soil in its loosest condition, e_{min} is the void ratio of the soil in its densest condition, e is the in-place void ratio, and void ratio is defined as the volume of the voids divided by the volume of the solids.

The cyclic and residual strengths of materials with this relative density can be estimated from various correlations related to Standard Penetration Test (SPT) blowcounts, N. In the correlations, it is usual to correct N-values to a confining stress of 1 tsf and an energy efficiency of 60 percent to obtain $N_{1,60}$. A summary of correlations between relative density and $N_{1,60}$ is shown in Figure B4 from Torrey et al. (1988). These correlations indicate $N_{1,60}$ ranges from about 11 to 16 for D_R ranging from 50 to 60 percent, and is about 14 for a relative density of 55 percent. The residual strength available after liquefaction can be estimated from correlations between field observations of slope failures and lateral spreading and corrected blowcounts. Figure B5 shows a recent correlation between $N_{1,60}$ and S_{us} for silty sands from Baziar and Dobry (1995), derived from earlier work by Seed (1987) and Seed and Harder (1990). The residual strength from Figure B5 for D_R of 55 percent, $N_{1,60}$ of 14 is about 500 psf, which far exceeds static driving shear stresses for the shelf and shelf break.

Baziar and Dobry (1995) have collected and summarized more extensive observational data to estimate residual strengths and extent of deformation that occur before liquefied materials restabilize. These summary plots are shown in Figure B6. Figure B6a indicates that a soil with $N_{1,60}$ of about 14 at a confining stress of about 1 tsf falls to the right of the boundary for large deformation potential in silty sand deposits. Consequently, even though the capping soils may liquefy during moderate to strong shaking, they would be expected to restabilize after deformations on the order of 3 ft or less.

Figure B6b shows the corresponding estimates of residual strengths for deposits that have experienced large deformations. These residual strengths are expressed as a function of vertical effective stress. Since the capping materials fall outside the large deformation potential range, the upper bound of $S_{us} = 0.2\ s_{vo}'$ is estimated to apply to the capping soils. This relationship was used to estimate minimum values of residual strength for the capping soils. Calculations are shown in Addendum A, Table A1.

The estimated residual strength of the cap is similar to the residual strength of existing sediments. Based on these strengths, safety factors against flow failure of a 1 to 3 ft thick cap would be greater than 2 on slopes of 5 degrees or less, and less than one for a slope angle of 18 degrees, as shown in Addendum A, Table A1.

Seismically-induced Shear Stresses, Liquefaction and Deformations

Wave Propagation Studies

Wave propagation analyses were performed to estimate the seismically-induced shear stresses that may occur in the cap and contaminated sediments. The program used was WESHAKE (Schnabel et al. 1972, Sykora et al. 1994), which is a one-dimensional, equivalent linear wave propagation code. WESHAKE is a PC version of the SHAKE program (Schnabel, Lysmer, and Seed, 1972), a commonly used computer program for evaluation of seismic stability. Four basic columns were used: 30-ft and 70-ft thicknesses of the marine sediments below the contaminated zone, and 3000 and 5000 fps shear wave velocity in the shelf bedrock. Cap thicknesses of 0, 1, 2 and 3 ft were used for each column. The material properties of the column sediments were estimated from data provided by Mr. Richard Wittkop (Port of Los Angeles Report by Fugro-McClelland 1992) and the WES shear wave velocity data base (Sykora 1987). These columns and estimated properties are shown in Figure B7. The relatively high unit weights assumed for the contaminated sediments is conservative and results in slightly higher computed shear stresses.

The accelerograms used for the wave propagation analyses are listed in Table A1. These records were readily available in the WESHAKE limited library of rock site records. (Other, more site specific records could be used if further analysis is needed.) These accelerograms were selected and scaled to simulate the ground motions estimated for the Port of Los Angeles, as listed in the report by Headland et al. (1995), for earthquakes of magnitude 7.4, 6.5 and 5.5. The computed accelerations and seismic shear stresses are provided in Addendum B. The wave propagation analyses indicate the offshore sediments and proposed cap will experience high cyclic shear stresses during moderate earthquakes of magnitude 5.5 to 6.5. Seismic shear stresses computed for the magnitude 7.4

event are only slightly greater than those computed for the magnitude 6.5 event. This indicates that the 6.5 and 7.4 events are approaching the limiting values of cyclic shear stresses that the soil columns can transmit. The 30-ft columns resulted in slightly higher cyclic stresses than the 70-ft columns. The 5,000 fps bedrock resulted in slightly higher stresses than the 3,000 fps bedrock. Stresses from the 30-ft column with 3,000 fps bedrock were used to carry out liquefaction and deformation calculations.

Liquefaction and Deformation Potential of Cap Materials

The cyclic strength of the cap materials can be estimated from $N_{1,60}$ correlations (Seed et al. 1984) shown in Figure B8. For a relative density of about 55 percent, equivalent $N_{1,60}$ of 14, and 15 percent fines, the cyclic strength ratio (CSR) from Figure B8 is about 0.2 for a magnitude 7.5 event. The cyclic strength is determined as:

$$t_{av} = s_{vo}{}' \, C_r \, CSR_{lab\ or\ chart} \, K_s \, K_a \, K_m \, K_{ocr} \qquad (3)$$

where t_{av} is the cyclic shear strength, C_r is a laboratory correction factor (C_r = 1 for chart strengths and cyclic simple shear tests; and C_r = 0.6 for triaxial test results; Seed 1979), $CSR_{lab\ or\ chart}$ is the cyclic strength ratio either from the chart in Figure B8 or from laboratory test results, K_s is an overburden stress factor that reflects the curvature in the cyclic strength envelope and is about 1.25 for the low confining stresses in the cap and contaminated soils (Seed and Harder 1990), K_a reflects the effect of non-zero initial stresses (assumed equal to 1 for this case; Seed and Harder 1990, Boulanger et al. 1991), K_m corrects to other magnitudes ($K_m = 173 \times (M)^{-2.56}$ from recent work by Idriss 1996), and K_{ocr} accounts for the effect of overconsolidation (K_{ocr} = 1 for the cap and 0.4 OCR + 0.6 for the contaminated sediments; Ishihara and Takatsu 1979).

Liquefaction would be expected to occur in the cap materials for the computed cyclic stress levels. On the relatively flat shelf slopes, these materials would be expected to restabilize after displacement of about 3 ft based on the work by Baziar and Dobry (1995). Liquefaction calculations are provided in Addendum A, Table A2.

Any deformations which may occur would not result in densification, since densification requires additional load on the surface. Past field data has indicated soils that have liquefied in the past tend to liquefy again and again. The liquefaction erases aging and stress history effects, and the material liquefies, deforms, and in a sense is redeposited through water, at very low confining stress. This scenario does not lend itself to considerable densification.

Liquefaction and Deformation Potential of Contaminated Sediments

The cyclic triaxial tests on the sediments reported by Lee and McArthur (1995) are based on a failure criterion of 20 percent cyclic shear strain. The excess pore water pressure behavior of the material under this loading is not reported. The laboratory cyclic strengths are well below the estimated cyclic shear stresses induced by magnitude 5.5 to 7.4 earthquakes, with or without a cap. If they are liquefiable in a pore pressure sense, these sediments would be expected to deform a few feet, similar to the cap materials, and then restabilize. Liquefaction calculations are provided in Addendum A, Table A2. Deformation calculations are provided in Addendum A, Table A3. These displacements are estimated from the Newmark chart developed by Makdisi and Seed (1977) for embankments. For the preliminary nature of this study, this chart, shown in Figure B9, should provide reasonable estimates of displacement for Newmark-type calculations.

The estimates of undrained shear strength available in the sediments based on the Lee and Edwards (1986) approach, applied in Lee and McArthur (1995), indicate higher strengths and Newmark-type deformations of less than 3 ft, even on the 18 degree slopes, for earthquakes of magnitude 5.5 to 6.5 . For a magnitude 7.4 event, displacements of 1 to 4 m would be estimated.

Weaknesses in the Existing Data and Analyses

Uncertainty in the available resistance

The laboratory tests were performed at confining stresses well in excess of the in situ stresses. In situ, the contaminated materials exist at natural water contents greater than the liquid limit. All of the triaxial tests were performed on samples with water contents less than the liquid limit. This raises the question: are the residual vane shear tests representative of the steady-state strength of the sediment? Accurately estimating this strength for both the sediment and the cap materials is the key to distinguishing catastrophic sliding (unacceptable performance) from limited seismic displacement (acceptable performance). Laboratory tests on undisturbed samples at low confining stresses could help reduce this uncertainty. An example of such testing is described in King (1975). An in situ test would be better, such as vane shear, since extraction of the samples exerts a stress history that may increase the residual strength.

There is no data for the capping materials. All estimates are based on correlations to anticipated conditions from past hydraulically placed silty sands. In situ testing of a similar deposit or test fill and laboratory testing at low confining stresses would better define the seismic strength and deformation potential of the capping materials.

Data from the Port of Los Angeles were used to estimate the engineering properties of the marine sediment below the contaminated zone. The Port of Los Angeles data indicate that this shelf deposit is not susceptible to liquefaction. Field investigations, as described by Lee and McArthur (1995), would verify the nature and liquefaction potential of the shelf deposits and provide a basis for evaluating past slope failures at the site with the Lee and Edwards (1986) approach.

Uncertainty in the applied loads

The wave propagation analyses used data from the Port of Los Angeles to estimate ground motions that could affect the site. Shear wave velocities of the deposits were estimated from this data and the WES shear wave velocity data base. Measurements of the actual velocities should be made to better estimate the cyclic loads. A larger number of accelerograms, better tailored to the site, should be used to estimate the range of cyclic shear stresses for the three earthquake events.

Conclusions

The conclusions from examination of the existing data and limited additional analyses are:

1. The contaminated sediments on slopes of up to 5 degrees are not susceptible to flow failure under existing conditions ($FS_{slide} > 8$).

2. The contaminated sediments on the steeper slopes are susceptible to flow failure under existing conditions ($FS_{slide} = 1$).

3. Addition of a cap with thickness up to 2 ft will not render the contaminated sediments susceptible to flow failure on slopes of 5 degrees or less ($1.5 < FS_{slide} < 4$).

4. Addition of a cap of any thickness on slopes of 11 degrees or greater will be susceptible to flow failure ($FS_{slide} < 1$).

5. If the contaminated sediments are susceptible to pore pressure development under cyclic loading, they are expected to liquefy if subjected to moderate earthquakes (Magnitude 5.5 or greater), but should restabilize after deforming about 3 ft or less (on slopes of 5 degrees or less).

6. A cap on slopes of up to 5 degrees will be susceptible to pore pressure development under cyclic loading, and will likely liquefy if subjected to moderate earthquakes (Magnitude 5.5 or greater), but should restabilize after deforming about 3 ft or less.

7. Additional field and laboratory investigations should be performed to determine the engineering characteristics of the materials below the contaminated zone and verify the residual shear strength of the contaminated sediments and capping materials.

References

Arumoli, K., Muraleetharan, K. K., Hossain, M. M. and Fruth, L. S. (1992). "VELACS-Laboratory testing program-soil data report," The Earth Technology Corporation, Project No. 90-0562.

Baziar, M. H. and Dobry, R. (1995). "Residual strength and large deformation potential of loose silty sands," ASCE Journal of Geotechnical Engineering, December 1995, Vol. 121, No. 12, pp. 896-906.

Bolt, B. A. and Seed, H. B. (1983). "Accelerogram selection report for Folsom Dam Project, California," Contract Report DACW 05-83-Q-0205, U.S. Army Engineer District, Sacramento, CA.

Boulanger, R. W., Seed, R. B., Chan, C. K, Seed, H. B. and Sousa, J. (1991). "Liquefaction behavior of saturated sands under uni-directional and bi-directional monotonic and cyclic simple shear loading," Geotechnical Engineering Report No. UCB/GT/91-08, University of California, Berkeley.

Castro, G. (1995). "Empirical methods in liquefaction evaluation," Primer Ciclo de Conferencias Internationales Leonardo Zeevaert, Mexico City, Mexico, November 1995.

Dobry, R., Taboada, V. and Liu, L. (1995). "Centrifuge modeling of liquefaction effects during earthquakes," First International Conference on Earthquake Geotechnical Engineering, Tokyo, Japan.

Headland, J. R., Lesnik, John R., McNeilan, Thomas W. and Hooper, James R. (1994). "Hydrodynamic & geotechnical assessment of the in situ capping alternative, Appendix G from Feasibility Study of Sediment Restoration Alternatives for the Southern California Natural Resource Damage Assessment," Expert Report by Michael R. Palermo, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Idriss, I. M. (1996). "Magnitude scaling factors," sponsored by the Federal Highways Administration, National Science Foundation and USAE Waterways Experiment Station, Proceedings to be published by National Center for Earthquake Engineering Research, Buffalo, NY.

Ishihara, K. and Takatsu (1979). “Effects of overconsolidation and K_o conditions on the liquefaction characteristics of sands, soils and foundations,” Journal of the Japanese Society on Soil Mechanics and Foundation Engineering, Vol. 19, No. 4.

King, J. B. (1975). “Characterization of viscoelastic properties of submarine sediments,” Master of Science Thesis Directed by Dr. Wayne A. Dunlap, Department of Civil Engineering, Texas A&M University, College Station, TX.

Lambe, T. W. and Whitman, R. V. (1969). Soil Mechanics, John Wiley and Sons, New York.

Lee, H. J. and Edwards, B. D. (1986). “Regional methods to assess offshore slope stability,” ASCE Journal of Geotechnical Engineering, May 1986, Vol. 112, No. 5, pp. 489-509.

Lee, H. J. and McArthur, W. G. (1995). “Stability of sediment on the Palos Verdes Margin, Southern California,” DRAFT Final Report to the Los Angeles County Sanitation Districts, USGS, Menlo Park, CA.

Makdisi, F. I. and Seed, H. B. (1977). “A simplified procedure for estimating earthquake-induced deformations in dams and embankments,” Report No. UBC/EERC-77/19, University of California, Berkeley.

Port of Los Angeles. (1992). “Younger marine sands,” Report No. 0901-2027, Vol. 1, by Fugro-McClelland, provided by Mr. Richard Wittkop.

Sasaki, Y., Tokida, K., Matsumoto, H. and Saya, S. (1991). “Experimental study on lateral flow of ground due to soil liquefaction,” Proceedings, 2nd International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, St. Louis, MO, Vol. I, pp. 263-270.

Schnabel, P., Lysmer J. and Seed, H. B. (1972). “SHAKE - A computer program for earthquake response analysis of horizontally layered sites,” Report No. UBC/EERC-72/12, University of California, Berkeley.

Seed, H. B. (1979). “Soil liquefaction and cyclic mobility evaluation for level ground during earthquakes,” ASCE Journal of Geotechnical Engineering, Vol. 105, No. 2, pp. 201-255.

Seed, H. B. (1987). “Hypothetical ground motion accelerogram for Ririe Dam,” Letter Report dated 5 August 1987.

Seed, H. B. (1987). “Design problems in soil liquefaction,” ASCE Geotechnical Journal, Vol. 113, No. 8, pp. 827-845.

Seed, H. B. and Harder, L. F. Jr. (1990). “SPT-based analysis of cyclic pore pressure generation and undrained residual strength,” H. Bolton Seed Memorial Proceedings, Vol. 2, May, Bitech Publishers Ltd., Berkeley, California, pp. 351-376.

Seed, H. B., Lee, K. L., Idriss, I. M. and Makdisi, F. (1973). "Analysis of the slides in the San Fernando Dams during the earthquake of Feb. 9, 1971," EERC Report No. 73-2, University of California, Berkeley.

Seed, H. B., Tokimatsu, K., Harder, L. F. Jr. and Chung, R. M. (1984). “Influence of SPT procedure in soil liquefaction resistance evaluations,” Journal of the Geotechnical Engineering Division, ASCE, Vol. 111, No. 12, pp. 861-878.

Schnabel, P. B., Lysmer, J. and Seed, H. B. (1972). "SHAKE A computer program for earthquake response analysis of horizontally layered sites," EERC Report No. 72-12, University of California, Berkeley.

Taboada, V. and Dobry, R. (1992). “Comparison tests for earth technology’s laboratory tests,” Report, Civil Engineering Department, Rensselaer Polytechnic Institute, Troy, NY.

Torrey, V. H. III, Dunbar, J. B. and Peterson, R. W. (1988). “Retrogressive failures in sand deposits of the mississippi river: report 1 field investigations, laboratory studies and analysis of the hypothesized failure mechanism,” Technical Report GL-88-9, USAE Waterways Experiment Station, Vicksburg, MS.

Sykora, D. W. (1987). “Creation of a Data Base of Seismic Shear Wave Velocities for Correlation Analysis,” Miscellaneous Paper GL-87-26, USAE Waterways Experiment Station, Vicksburg, MS.

Sykora, D. W., Wahl, R. E., Wallace, D. C. and Yule, D. E. (1994). “USACE geotechnical earthquake engineering software, Report 2: WESHAKE for personal computers,” Instruction Report GL-94, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Table B1
Earthquake Parameters and Records Used in Weshake Response Analysis

Port of Los Angeles Earthquake Event	Record Used in WESHAKE Analyses
Operational Level Magnitude = 5.5 PHGA = 0.24g	#7* Coyote Lake earthquake 8/6/79, Gilroy No. 1 Magnitude = 5.8 PHGA of record = 0.113g PHGA scaling factor = 2.1
	#11 Nahanni NWT. aftershock 1/23/85, Iverson site Magnitude = 5.4 PHGA of record = 0.223g PHGA scaling factor = 1.1
Contingency Level Magnitude = 6.5 PHGA = 0.45g	#14 Folsom Dam design record A (Bolt and Seed 1983) Magnitude = 6.5 PHGA of record = 0.35g PHGA scaling factor = 1.29
	#15 Folsom Dam design record B (Bolt and Seed 1983) Magnitude = 6.5 PHGA of record = 0.35g PHGA scaling factor = 1.29
Maximum Credible Magnitude = 7.5 PHGA = 0.6g	#22 Ririe Dam design record (Seed 1987) Magnitude = 7.5 PHGA = 1.17g PHGA scaling factor = 0.51

*Note: # indicates record number in WESHAKE library of rock site accelerograms

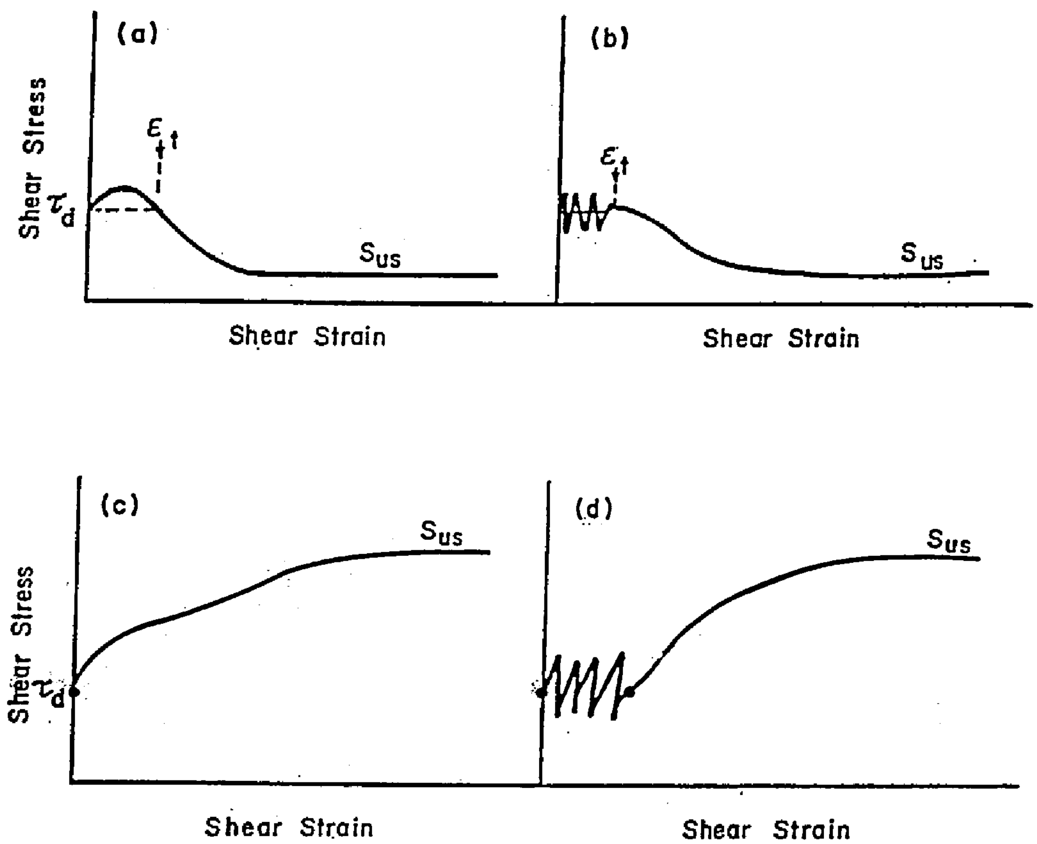


Figure B1. Monotonic and cyclic Loading of a Saturated Sand (after Castro 1995)

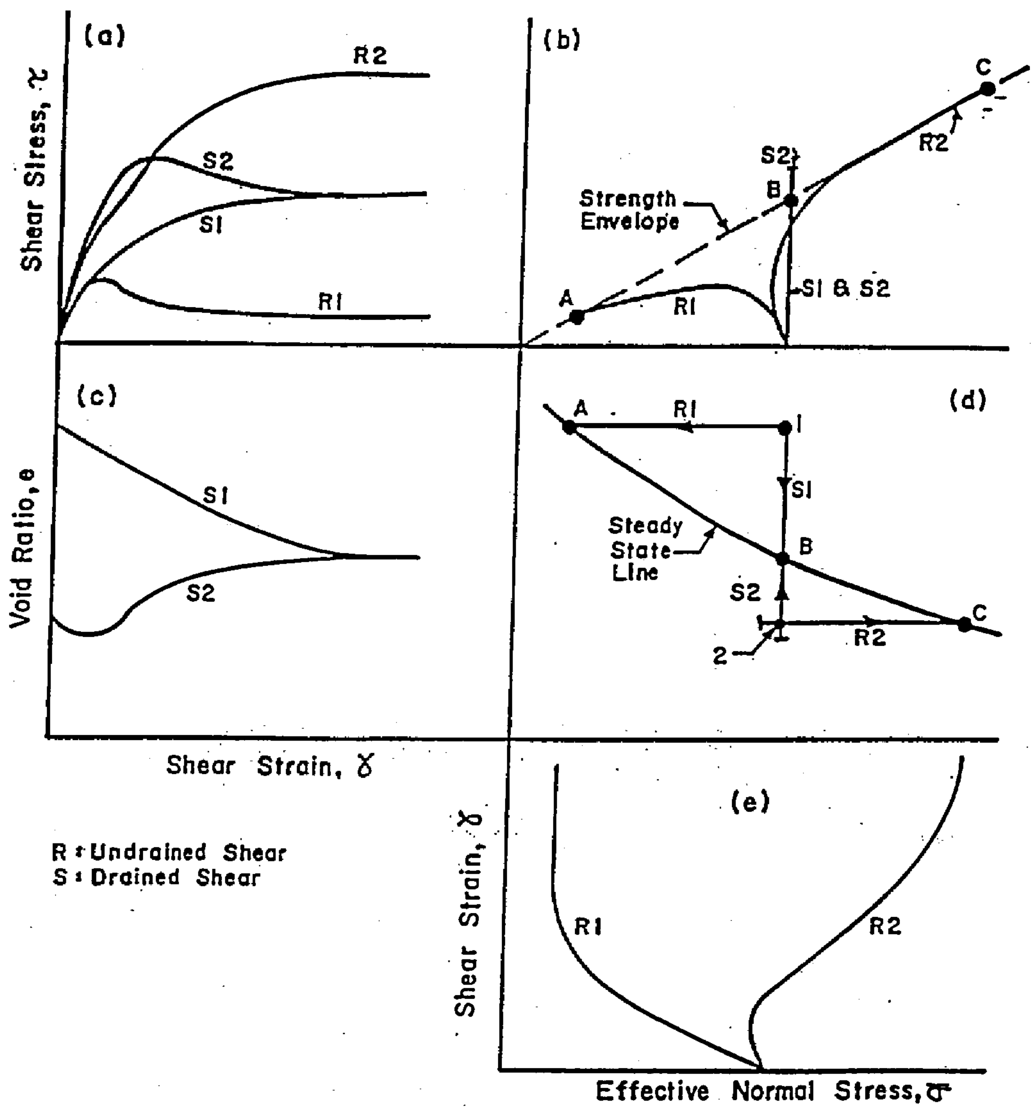


Figure B2. Stress Strain of a Sand in Simple Shear (after Castro 1995)

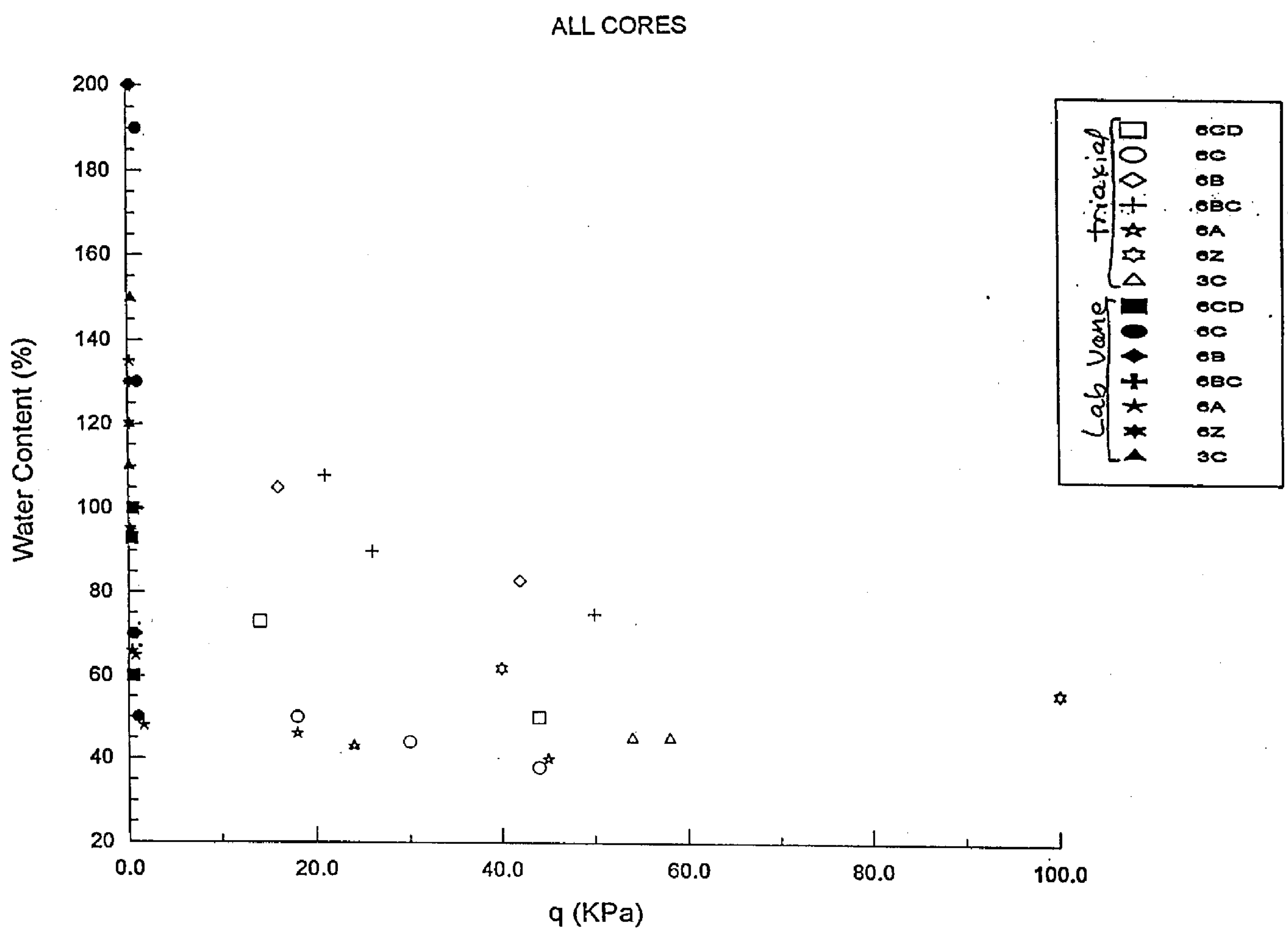


Figure B3. Residual Strength of Undisturbed Samples Plotted Against Water Content (data from Lee and McArthur 1995)

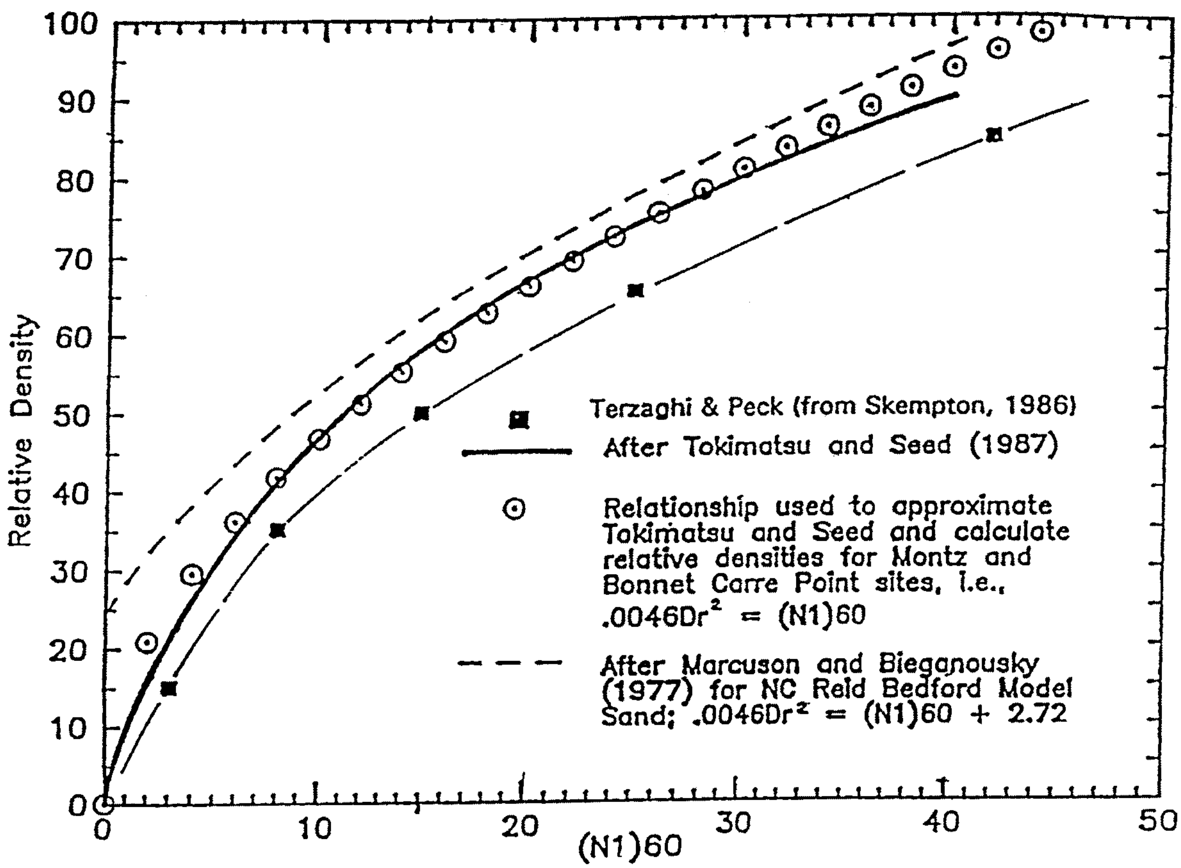


Figure B4. Proposed Relationships between Standard Penetration Resistance and Relative Density (after Torrey et al. 1988)

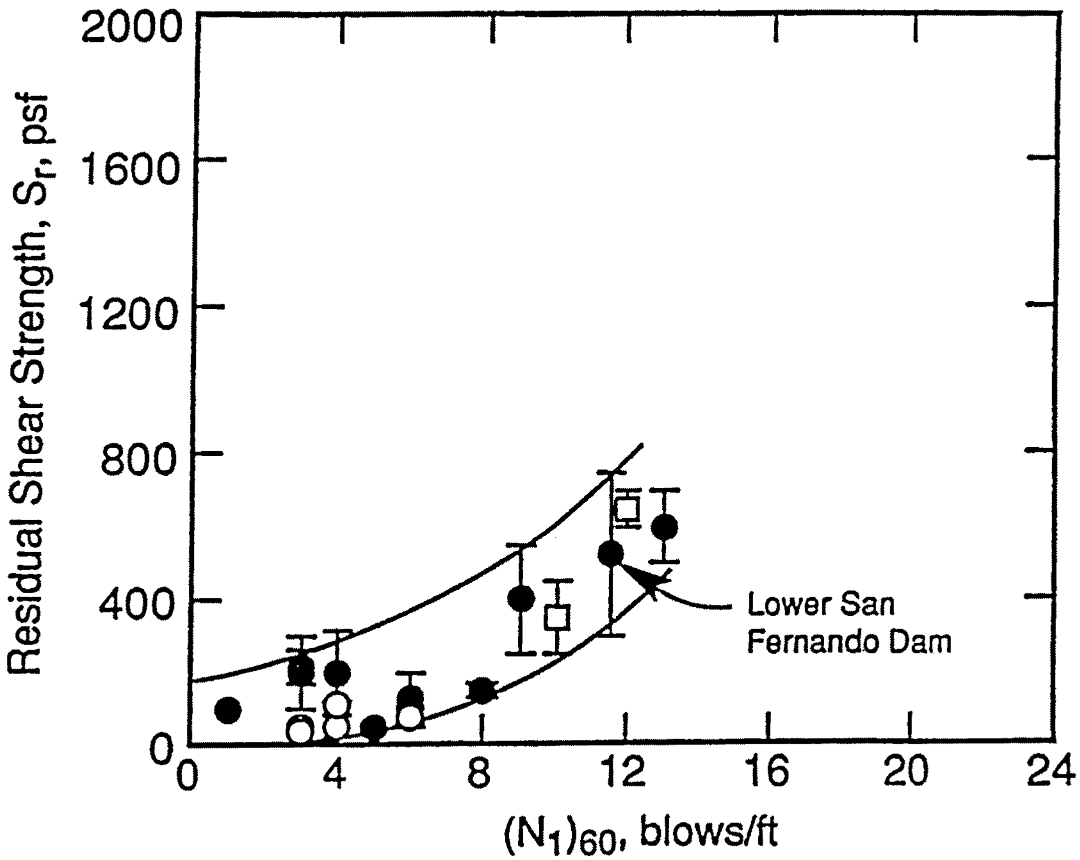


Figure B5. Residual shear strength of liquefied soils correlated to Standard Penetration resistance (after Seed and Harder 1990, Baziar and Dobry 1995)

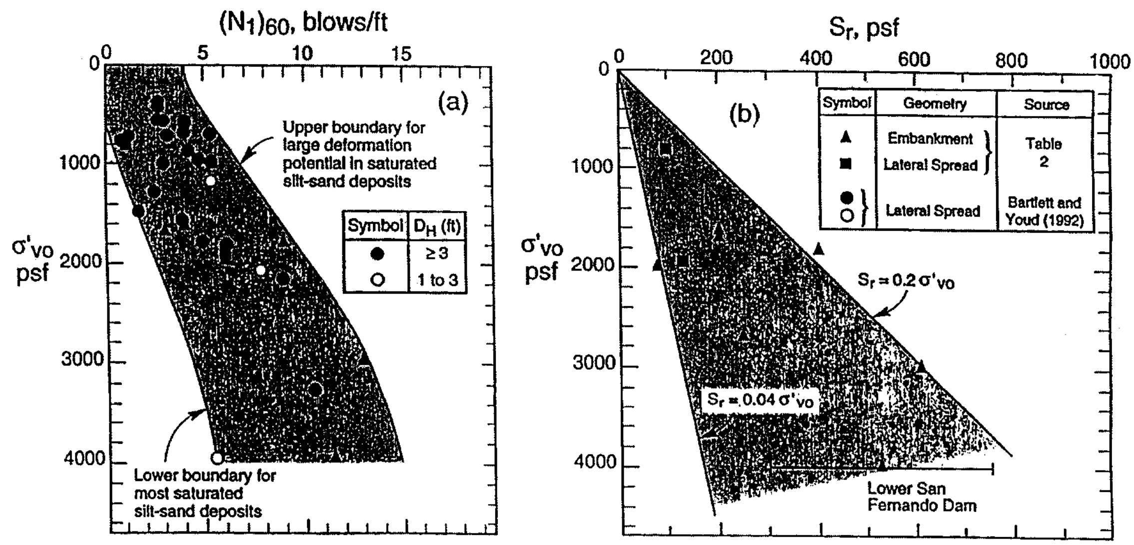


Figure B6. Charts relating Standard Penetration resistance and residual shear strength of liquefied soils to vertical effective stress, for non-gravelly silt-sand deposits that have experienced large deformations (after Bazier and Dobry 1995)

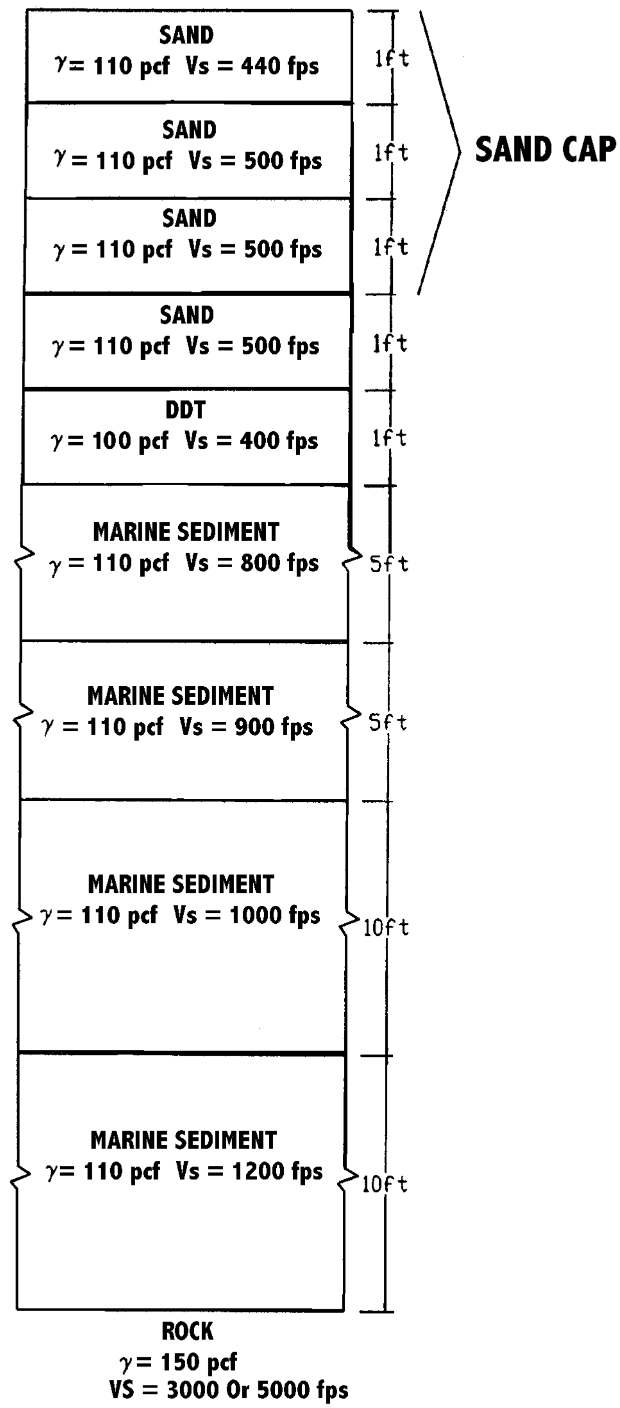


Figure B7a. Soil column used in WESHAKE analyses with 30 ft of marine sediments

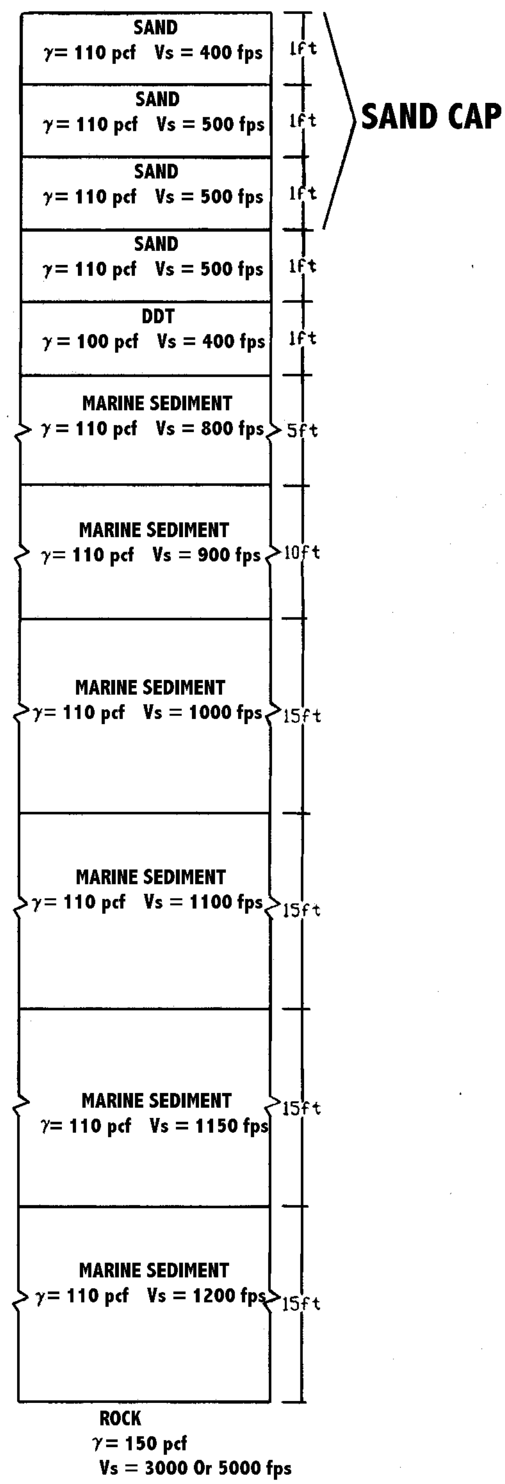


Figure B7b. Soil column used in WESHAKE analyses with 70 ft of marine sediments

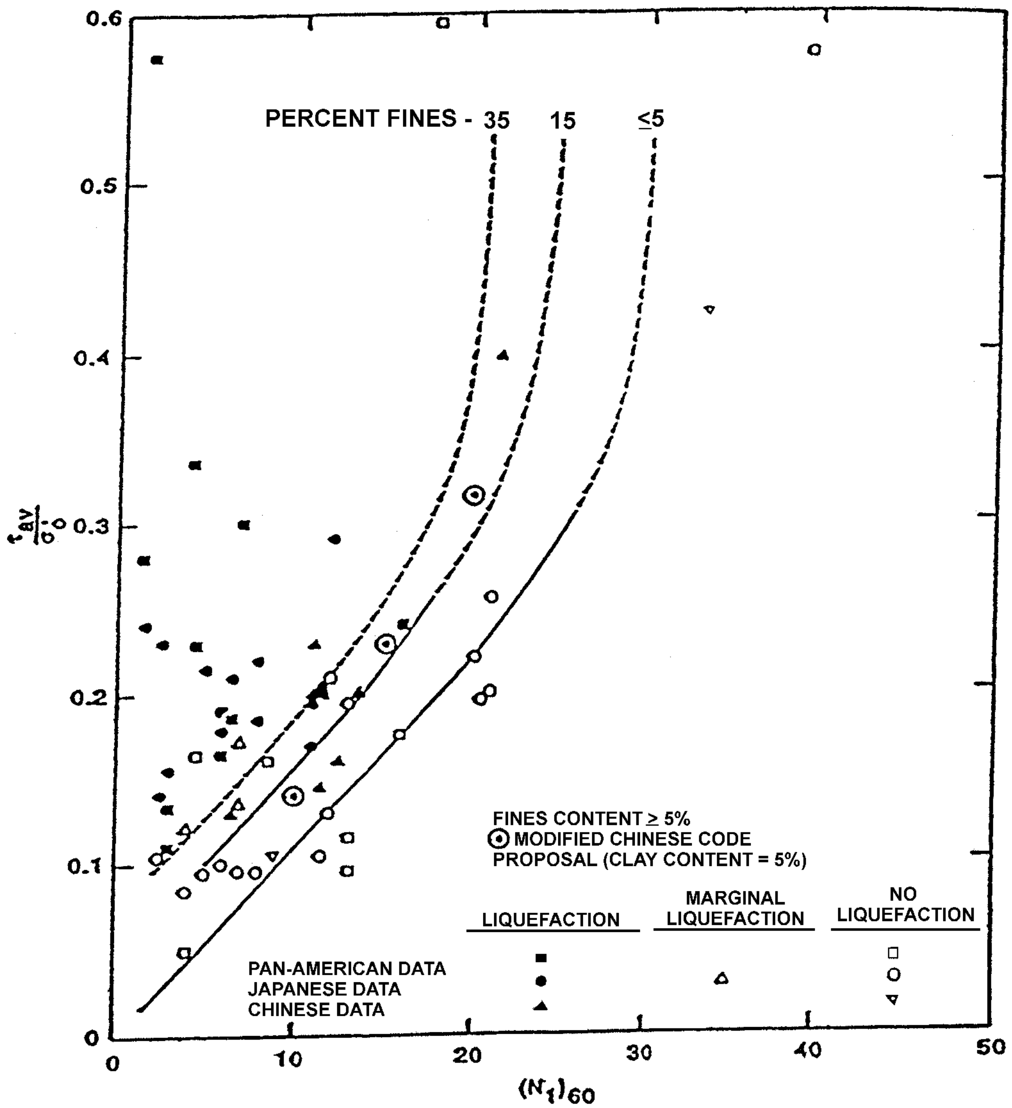


Figure B8. Relationship cyclic stress ratios causing liquefaction and Standard Penetration resistance for silty sands for Magnitude 7.5 earthquakes (after Seed et al. 1984)

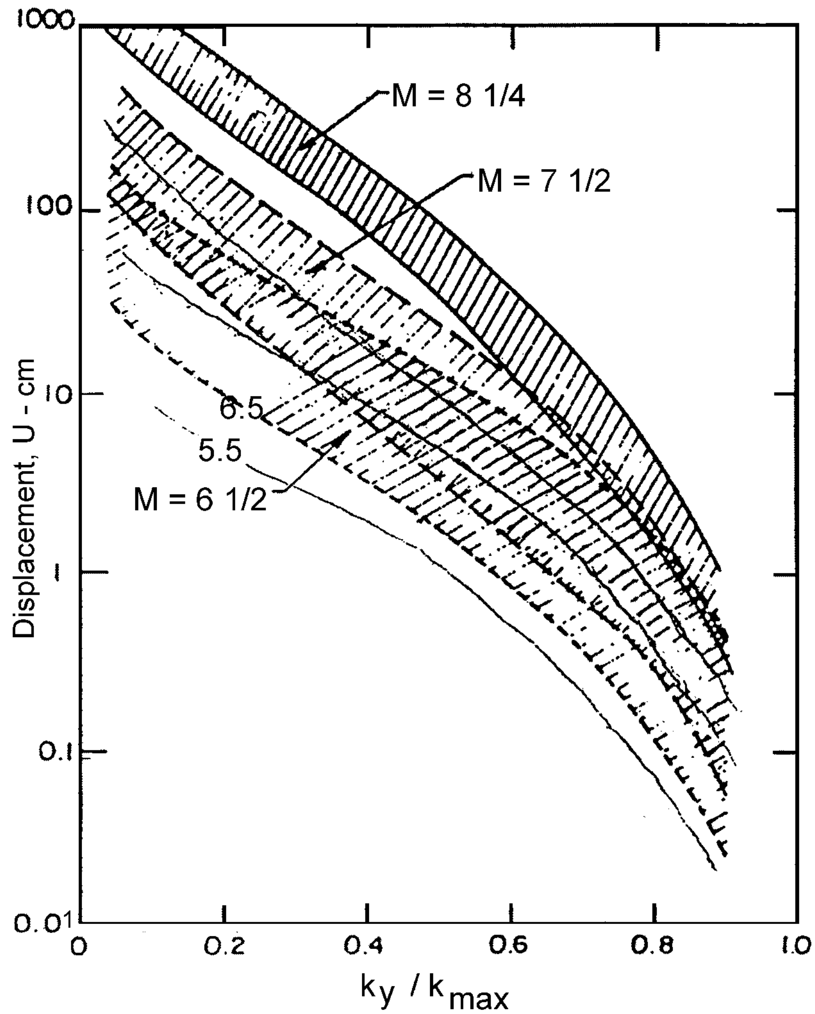


Figure B9. Variation of permanent displacement with yield acceleration for various magnitudes (after Makdisi and Seed 1977)

ADDENDUM A TO APPENDIX B

CALCULATION TABLES

Table A1. Safety Factors Against Flow Failure

Table A2. Safety Factors Against Liquefaction

Table A3. Displacement Calculations

SUBJECT: Table A1: Static Driving Stress (τ_{ho}), Residual Strength ($S_{u\,vane}$) and Safety Factors Against Flow Failure (FS_{flow})

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Table A1a. Cap Materials (stresses in kPa)

Slope Angle $\alpha°$	Vertical Effective Stress for Cap Thicknesses 1-3 ft.			Static Driving Stress $\tau_{ho} = \sigma_v' \sin\alpha$			Residual Strength				Factor of Safety Against Flow Failure (FS_{flow}) using minimum residual strength		
							Typical	Minimum					
	$\sigma_{v,1'}'$	$\sigma_{v,2'}'$	$\sigma_{v,3'}'$	1ft	2ft	3ft		1ft	2ft	3ft	1ft	2ft	3ft
1.5	1.9	3.8	5.7	0.05	0.10	0.15	>10	0.38	0.76	1.14	7.5	7.5	7.5
5	1.9	3.8	5.7	0.17	0.33	0.50	>10	0.38	0.76	1.14	2.2	2.3	2.3
18	1.9	3.8	5.7	0.59	1.17	1.76	>10	0.38	0.76	1.14	0.65	0.65	0.65

Table A1b. Contaminated Sediments (stresses in kPa)

Core	Slope Angle $\alpha°$	Vertical Effective Stress for Cap Thicknesses 0-3 ft.				Static Driving Stress $\tau_{ho} = \sigma_v' \sin\alpha$				Sensitivity		Residual Strength $S_{u,vane,resid.}$		Factor of Safety Against Flow Failure, FS_{flow}: Typical $S_{u,vane,resid.}$				Min. $S_{u,vane,resid.}$			
		$\sigma_{v,0'}'$	$\sigma_{v,1'}'$	$\sigma_{v,2'}'$	$\sigma_{v,3'}'$	0ft	1ft	2ft	3ft	typ.	max	typ.	min.	0ft	1ft	2ft	3ft	0ft	1ft	2ft	3ft
6CD	1.47	1.03	2.93	4.83	6.73	0.03	0.08	0.12	0.17	4	7	0.5	0.3	16	6.25	4.2	2.9	10	3.8	2.5	1.76
6C	4.24	0.8	2.7	4.6	6.5	0.06	0.20	0.34	0.48	3	6	1.3	0.5	22	6.5	3.8	2.6	8.3	2.5	1.5	1.04
6B	18.2	0.47	2.37	4.27	6.17	0.15	0.74	1.33	1.93	8	12	0.25	0.25	1.67	0.3	0.2	0.1	1.67	<1	<1	<1
6A	15.15	1.61	3.51	5.41	7.31	0.42	0.92	1.41	1.91	5	8	0.4	0.4	1	0.4	0.3	0.2	1	<1	<1	<1
6Z	13.87	0.84	2.74	4.64	6.54	0.20	0.66	1.11	1.57	8	18	0.25	0.2	1.2	0.4	0.23	0.16	1	<1	<1	<1
3C	1.35	1.5	3.4	5.3	7.2	0.04	0.08	0.12	0.17	6	20	0.3	0.1	7.5	3.7	2.5	1.8	2.5	1.25	0.8	0.6

SUBJECT: Table A2. Liquefaction Calculations

$\tau_{cyclic\ resistance} = \sigma_v' \times 0.6 \times CSR_{lab}\big|_{\tau_{max}}^{\tau_{Cr}} \big|_{for\ M}^{No.\ cycles} \times K_\sigma \times \left[\frac{K_M\ for}{N_{1,60}}\right] \times K_{OCR} \times K_\alpha$ $\varepsilon_{1.25}$ $\varepsilon_{DA\,OCR\,+0.6}$ 1.0 at low α

COMPUTED BY: Cap: $D_r \approx 55\% \rightarrow N_{1,60} \sim 14$ w/15% fines

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DATE:

Core	Depth Z (cm)	Vertical Effective Stress (kPa) $\sigma'_{v,0'}$	$\sigma'_{v,1'}$	$\sigma'_{v,2'}$	$\sigma'_{v,3'}$	$\tau_{induced\ cyclic}$ M=5.5 (kPa) 0'	1'	2'	3'	$\tau_{induced\ cyclic}$ M=6.5 (kPa) 0'	1'	2'	3'	$\tau_{induced\ cyclic}$ M=7.4 (kPa) 0'	1'	2'	3'	Estimated $0.6 \times CSR_{lab}\big|_{\tau_{max}}$ n for M 5.5	6.5	7.4	$\sigma'_{v\,max}$ (kPa)
Cap*	1',2',3'	0	1.9	3.8	5.7	0	2.0	3.6	6.6	0	3.75	6.1	9.75	0	3.75	6.4	10.4	0.3*	0.24*	0.2*	—
6CD	25.5	1.03	2.93	4.83	6.73	1.65	3.75	6.0	8.5	2.60	5.8	9.25	12.75	2.75	5.8	9.70	13.25	0.33	0.24	0.21	6.53
6C	37	0.8	2.70	4.60	6.50	2.35	4.5	6.9	9.25	3.60	7.0	10.15	13.65	4.0	7.0	10.7	14.50	0.46	0.38	0.34	15.3
6B	26	0.47	2.37	4.27	6.17	1.65	3.75	6.0	8.5	2.60	6.8	9.25	12.75	2.75	5.8	9.7	13.25	0.33	0.27	0.25	5.57
6A	31.5	1.61	3.51	5.41	7.31	2.0	4.0	6.5	8.9	3.0	6.25	9.5	13.15	3.3	6.25	10.15	13.85	0.3	0.28	0.28	10.61
6Z	31	0.84	2.74	4.64	6.54	2.0	4.0	6.5	8.9	3.0	6.25	9.5	13.15	3.3	6.25	10.15	13.85	0.33	0.24	0.21	8.14
3C	30	1.5	3.40	5.37	7.20	2.0	4.0	6.5	8.9	3.0	6.25	9.5	13.15	3.3	6.25	10.15	13.85	0.45	0.27	0.21	6.0

* Cyclic strengths estimated from $N_{1,60}$ correlations

Core	$\tau_{cyclic\ resistance}$ M=5.5 (kPa) 0'	1'	2'	3'	$\tau_{cyclic\ resistance}$ M=6.5 (kPa) 0'	1'	2'	3'	Factor of Safety Against Liquefaction, FS_L M=5.5 0'	1'	2'	3'	FS_L M=6.5 0'	1'	2'	3'
Cap*	–	1.09	2.20	3.30	–	0.68	1.36	2.05	–	0.55	0.62	0.49	–	0.18	0.23	0.22
6CD	1.33	1.80	2.27	2.78	0.97	1.31	1.65	2.02	0.81	0.48	0.38	0.33	0.37	0.23	0.18	0.16
6C	3.80	4.45	5.11	5.76	3.14	3.68	4.22	4.76	1.62	0.99	0.74	0.62	0.87	0.53	0.42	0.35
6B	1.04	1.51	1.98	2.55	0.85	1.23	1.62	2.08	0.63	0.40	0.33	0.30	0.33	0.21	0.17	0.16
6A	1.95	2.38	2.81	3.24	1.82	2.22	2.62	3.02	0.98	0.60	0.43	0.36	0.61	0.36	0.28	0.23
6Z	1.55	2.02	2.49	2.96	1.13	1.47	1.81	2.15	0.78	0.50	0.38	0.33	0.38	0.24	0.19	0.16
3C	1.86	2.50	3.14	4.05	1.11	1.50	1.88	2.43	0.93	0.63	0.48	0.46	0.37	0.24	0.20	0.18

Table A3. Displacement Calculations

SUBJECT: $S_{ur} = \bar{\sigma}'_v A_c A_r U S (OCR)^m = 0.8 \bar{\sigma}'_v A_r S (OCR)^{0.8}$

$K_c = (S_{ur} - \sigma'_{v_f} \sin\alpha)/\bar{\sigma}_v$

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DATE: Page 1 of 2

Core	Z (cm)	α°	σ'_{vo}	σ'_{vc}	σ'_{vm}	1-ft cap σ'_{vf}	1-ft cap σ_{vf}	S	Ar_4	Ar_{10}	Ar_{14}	M=5.5 CSR_4	M=6.5 CSR_{10}	M=7.4 CSR_{14}	Sur no cap N=4	Sur no cap N=10	Sur no cap N=14	Sur 1' cap N=4	Sur 1' cap N=10	Sur 1' cap N=14
6CD	25.5	1.47	1.03	5.5	6.53	2.93	8.86	0.43	1.25	0.93	0.81	~0.55	0.40	~0.35	1.94	1.29	1.26	2.13	1.59	1.38
6C	37	4.24	0.8	14.5	15.3	2.70	9.85	0.51	1.51	1.19 (1.24)	1.10	0.77	0.63	0.56	5.22	4.12	3.80	6.66	5.25	4.85
6BC																				
6B	26	18.2	0.47	5.1	5.57	2.37	8.34	0.46	1.15	1.0	0.91	>0.53	0.45	0.42	1.44	1.25	1.14	1.99	1.73	1.57
6A	31.5	15.15	1.61	9.0	10.61	3.51	10.07	0.49	1.0	0.94	0.94	>0.49	0.47	0.46	2.86	2.68	2.68	3.33	3.13	3.13
6Z	31	13.87	0.84	7.3	8.14	2.74	9.25	0.38	1.45	1.05	0.92	0.55	0.40	0.35	2.28	1.65	1.45	2.89	2.09	1.83
3C	30	1.35	1.5	4.5	6.0	3.40	9.80	0.58	1.29	0.77	0.60	0.75	0.45	0.35	2.72	1.62	1.27	3.21	1.91	1.49

Core	Z (cm)	α°	σ'_{vo}	σ'_{vc}	σ'_{vm}	2-ft cap σ'_{vf}	2-ft cap σ_{vf}	3-ft cap σ'_{vf}	3-ft cap σ_{vf}	S	Ar_4	Ar_{10}	Ar_{14}	Sur 2' cap N=4	Sur 2' cap N=10	Sur 2' cap N=14	Sur 3' cap N=4	Sur 3' cap N=10	Sur 3' cap N=14
6CD	25.5	1.47	1.03	5.5	6.53	4.83	13.95	6.73	19.05	0.43	1.25	0.93	0.81	2.64	1.97	1.71	2.89	2.15	1.88
6C	37	4.24	0.8	14.5	15.3	4.60	14.95	6.50	20.05	0.51	1.51	1.19	1.10	7.41	5.84	5.40	7.94	6.26	5.79
6B	26	18.2	0.47	5.1	5.57	4.27	13.44	6.17	18.54	0.46	1.15	1.0	0.91	2.24	1.94	1.77	2.61	2.27	2.07
6A	31.5	15.15	1.61	9.0	10.61	5.41	15.17	7.31	20.27	0.49	1.0	0.94	0.94	3.63	3.42	3.42	3.86	3.63	3.63
6Z	31	13.87	0.84	7.3	8.14	4.64	14.35	6.54	19.45	0.38	1.45	1.05	0.92	3.21	2.32	2.03	3.43	2.49	2.18
3C	30	1.35	1.5	4.5	6.0	5.30	14.90	7.20	20.0	0.58	1.29	0.77	0.60	3.50	2.09	1.63	4.31	2.57	2.00

Core	Z (cm)	α°	0-ft cap σ'_{vf}	0-ft cap σ_{vf}	Sur_4	Sur_{10}	Sur_{14}	Kc_4	Kc_{10}	Kc_{14}	1-ft cap σ'_{vf}	1-ft cap σ_{vf}	Sur_4	Sur_{10}	Sur_{14}	Kc_4	Kc_{10}	Kc_{14}
6CD	25.5	1.47	1.03	3.75	1.94	1.29	1.26	0.51	0.34	0.34	2.93	8.85	2.13	1.59	1.38	0.23	0.17	0.15
6C	37	4.24	0.8	4.75	5.22	4.12	3.80	1.09	0.85	0.79	2.70	9.85	6.66	5.25	4.85	0.66	0.51	0.47
6B	26	18.2	0.47	3.24	1.44	1.25	1.14	0.40	0.34	0.31	2.37	8.34	1.99	1.73	1.57	0.15	0.12	0.10
6A	31.5	15.15	1.61	4.97	2.85	2.68	2.68	0.49	0.45	0.45	3.51	10.07	3.33	3.13	3.13	0.24	0.22	0.22
6Z	31	13.87	0.84	4.15	2.28	1.65	1.45	0.50	0.35	0.30	2.74	9.25	2.89	2.09	1.83	0.24	0.15	0.13
3C	30	1.35	1.5	4.70	2.72	1.62	1.27	0.57	0.34	0.24	3.40	9.80	3.21	1.91	1.49	0.32	0.19	0.14

Core	Z	α	2-ft cap σ'_{vf}	2-ft cap σ_{vf}	Sur_4	Sur_{10}	Sur_{14}	Kc_4	Kc_{10}	Kc_{14}	3-ft cap σ'_{vf}	3-ft cap σ_{vf}	Sur_4	Sur_{10}	Sur_{14}	Kc_4	Kc_{10}	Kc_{14}
6CD	25.5	1.47	4.83	13.95	2.64	1.97	1.71	0.18	0.13	0.11	6.73	19.05	2.89	2.15	1.88	0.14	0.10	0.09
6C	37	4.24	4.60	14.95	7.41	5.84	5.40	0.47	0.37	0.34	6.50	20.05	7.94	6.26	5.79	0.37	0.29	0.26
6B	26	18.2	4.27	13.44	2.24	1.94	1.77	0.07	0.05	0.03	6.17	18.54	2.61	2.27	2.07	0.04	0.02	0.01
6A	31.5	15.15	5.41	15.17	3.63	3.42	3.42	0.15	0.13	0.13	7.31	20.27	3.86	3.63	3.63	0.10	0.08	0.08
6Z	31	13.87	4.64	14.35	3.21	2.32	2.03	0.15	0.08	0.06	6.54	19.45	3.43	2.49	2.18	0.10	0.05	0.03
3C	30	1.35	5.30	14.90	3.50	2.09	1.63	0.23	0.13	0.10	7.20	20.0	4.31	2.57	2.00	0.21	0.12	0.09

SUBJECT: Table A3. Displacement calculations (concluded)

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DATE: 11/17/95

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0-ft cap

Core	Z	σ_{vo}	K_{c4}	K_{c10}	K_{c14}	$\tau_{5.5}$	$\tau_{6.5}$	$\tau_{7.4}$	$K_{5.5}$	$K_{6.5}$	$K_{7.4}$	Kc/Kmax 5.5	Kc/Kmax 6.5	Kc/Kmax 7.4	$u_{5.5}$	$u_{6.5}$	$u_{7.4}$
						τcyclic			Kmax						Displacement (cm)		
6CD	25.5	3.75	0.51	0.34	0.34	1.65	2.60	2.75	0.44	0.69	0.73	1.16	0.49	0.46	0	5	11.7
6C	37	4.75	1.09	0.55	0.79	2.35	3.60	4.0	0.49	0.76	0.84	2.20	1.12	0.94	0	0	<0.1
6B	26	3.24	0.40	0.34	0.31	1.65	2.60	2.75	0.51	0.80	0.85	0.79	0.42	0.37	<0.1	7.6	23.4
6A	31.5	4.97	0.49	0.45	0.45	2.0	3.0	3.3	0.40	0.60	0.66	1.22	0.75	0.68	0	0.8	2.6
6Z	31	4.15	0.50	0.35	0.30	2.0	3.0	3.1	0.48	0.72	0.80	1.04	0.48	0.38	0	5.5	23.4
3C	30	4.70	0.57	0.34	0.26	2.0	3.0	3.3	0.43	0.64	0.70	1.34	0.53	0.37	0	4.2	23.4

1-ft cap

Core	Z	σ_{vo}	K_{c4}	K_{c10}	K_{c14}	$\tau_{5.5}$	$\tau_{6.5}$	$\tau_{7.4}$	$K_{5.5}$	$K_{6.5}$	$K_{7.4}$	Kc/Kmax 5.5	Kc/Kmax 6.5	Kc/Kmax 7.4	$u_{5.5}$	$u_{6.5}$	$u_{7.4}$
						τcy			Kmax						u		
6CD	25.5	8.85	0.23	0.17	0.15	3.75	5.8	5.8	0.42	0.66	0.66	0.54	0.26	0.23	0.8	18.6	63.1
6C	37	9.85	0.66	0.51	0.47	4.5	7.0	7.0	0.46	0.71	0.71	1.44	0.72	0.66	0	1.0	2.8
6B	26	8.34	0.15	0.12	0.10	3.75	5.8	5.8	0.45	0.70	0.70	0.33	0.17	0.14	2.6	29.2	115
6A	31.5	10.07	0.24	0.22	0.22	4.0	6.25	6.25	0.40	0.62	0.62	0.60	0.35	0.35	0.5	11.7	23.4
6Z	31	9.25	0.24	0.15	0.13	4.0	6.25	6.25	0.43	0.68	0.68	0.56	0.22	0.19	0.7	22.4	77.6
3C	30	9.80	0.32	0.19	0.14	4.0	6.25	6.25	0.41	0.64	0.64	0.78	0.30	0.22	<0.1	46.0	63.1

2-ft cap

Core	Z	σ_{vo}	K_4	K_{10}	K_{14}	τcy 5.5	τcy 6.5	τcy 7.4	Kmax 5.5	Kmax 6.5	Kmax 7.4	Kc/Kmax 5.5	Kc/Kmax 6.5	Kc/Kmax 7.4	u 5.5	u 6.5	u 7.4
6CD	25.5	13.95	0.18	0.13	0.11	6.0	9.25	9.70	0.43	0.66	0.70	0.42	0.20	0.16	1.7	26.5	93.3
6C	37	14.95	0.47	0.37	0.34	6.9	10.15	10.7	0.46	0.68	0.72	1.02	0.54	0.48	0	4.0	11.2
6B	26	13.44	0.07	0.05	0.03	6.0	9.25	9.70	0.45	0.69	0.72	0.16	0.07	0.04	6.3	55.0	282
6A	31.5	15.17	0.15	0.13	0.13	6.5	9.5	10.15	0.43	0.63	0.67	0.35	0.21	0.19	2.4	26.0	77.6
6Z	31	14.35	0.15	0.08	0.06	6.5	9.5	10.15	0.45	0.66	0.71	0.33	0.12	0.08	2.6	39.8	195
3C	30	14.90	0.23	0.13	0.10	6.5	9.5	10.15	0.44	0.64	0.68	0.53	0.20	0.15	0.8	26.0	115

3-ft cap

Core	Z	σ_{vo}	K_4	K_{10}	K_{14}	τcy 5.5	τcy 6.5	τcy 7.4	Kmax 5.5	Kmax 6.5	Kmax 7.4	Kc/Kmax 5.5	Kc/Kmax 6.5	Kc/Kmax 7.4	u 5.5	u 6.5	u 7.4
6CD	25.5	19.05	0.14	0.10	0.09	8.5	12.75	13.25	0.45	0.67	0.70	0.31	0.15	0.13	2.9	33.5	123
6C	37	20.05	0.37	0.29	0.26	9.25	13.65	14.60	0.46	0.68	0.72	0.80	0.43	0.36	<0.1	7.9	23.4
6B	26	18.54	0.04	0.02	0.01	8.5	12.75	13.25	0.46	0.69	0.71	0.09	0.03	0.01	9.3	77.6	400
6A	31.5	20.77	0.10	0.08	0.08	8.9	13.15	13.85	0.44	0.65	0.68	0.23	0.12	0.12	4.1	39.8	141
6Z	31	19.45	0.10	0.05	0.03	8.9	13.15	13.85	0.46	0.68	0.71	0.22	0.07	0.04	4.2	55.0	282
3C	30	20.0	0.21	0.12	0.09	8.9	13.15	13.85	0.45	0.66	0.69	0.47	0.18	0.13	1.3	29.2	123

ADDENDUM B TO APPENDIX B

CYCLIC SHEAR
FROM WESHAKE CALCULATIONS

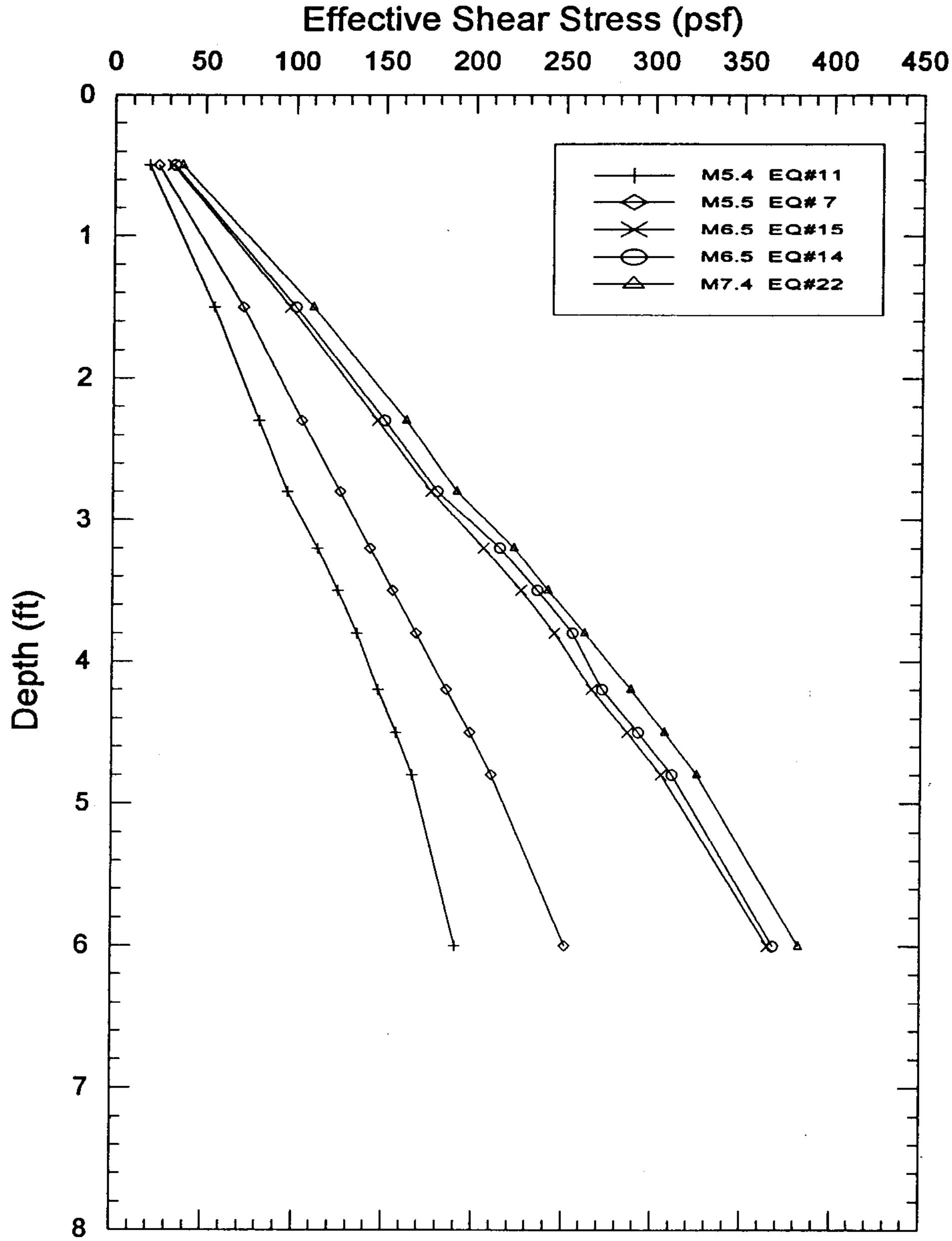


Figure B-1:
Cyclic Shear Stresses
WESHAKE Calculations
3-ft sand cap
30 ft. marine sediments
Rock V_s = 5000 fps

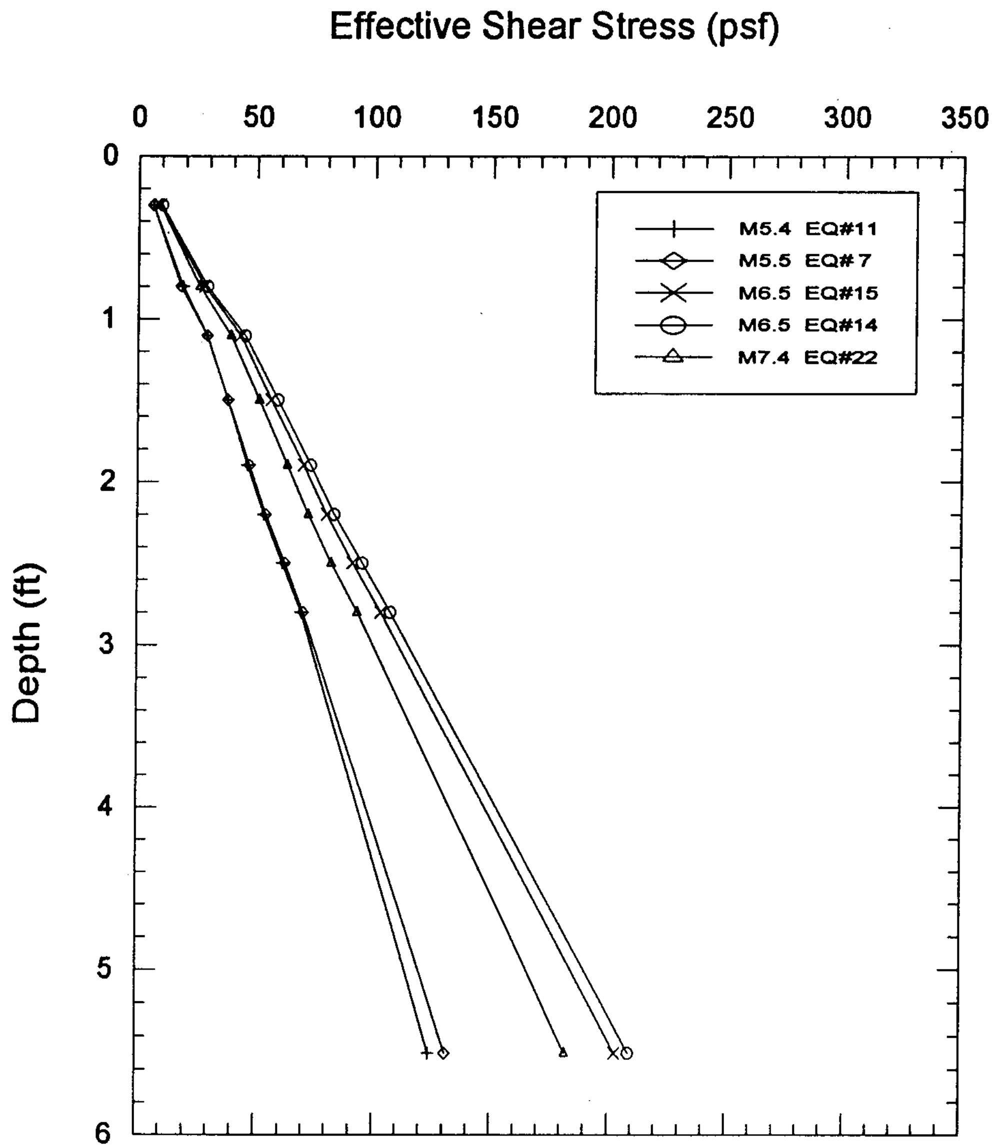


Figure B-2
Cyclic Shear Stresses
WESHAKE Calculations
1-ft sand cap
75 ft. marine sediments
Rock V_s = 3000 fps

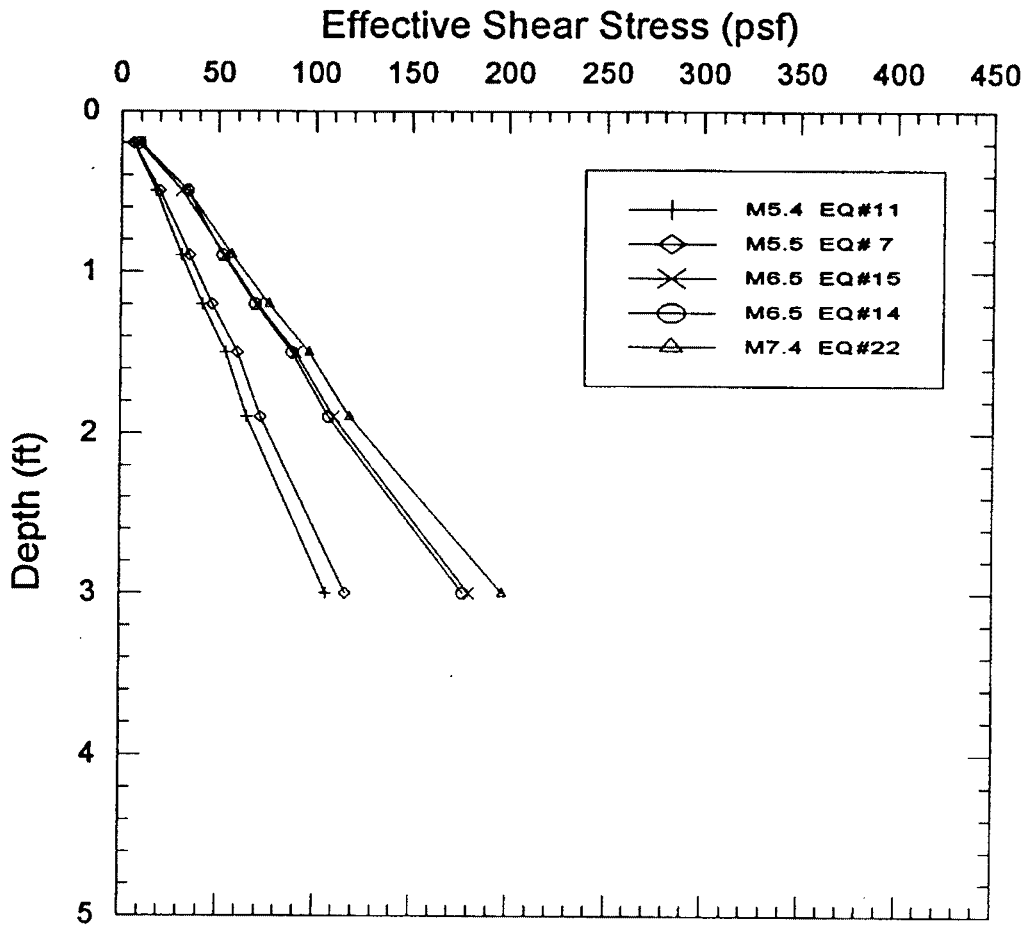


Figure B-3.
Cyclic Shear Stresses
WESHAKE Calculations
0-ft sand cap
30 ft. marine sediments
Rock V_s = 3000 fps

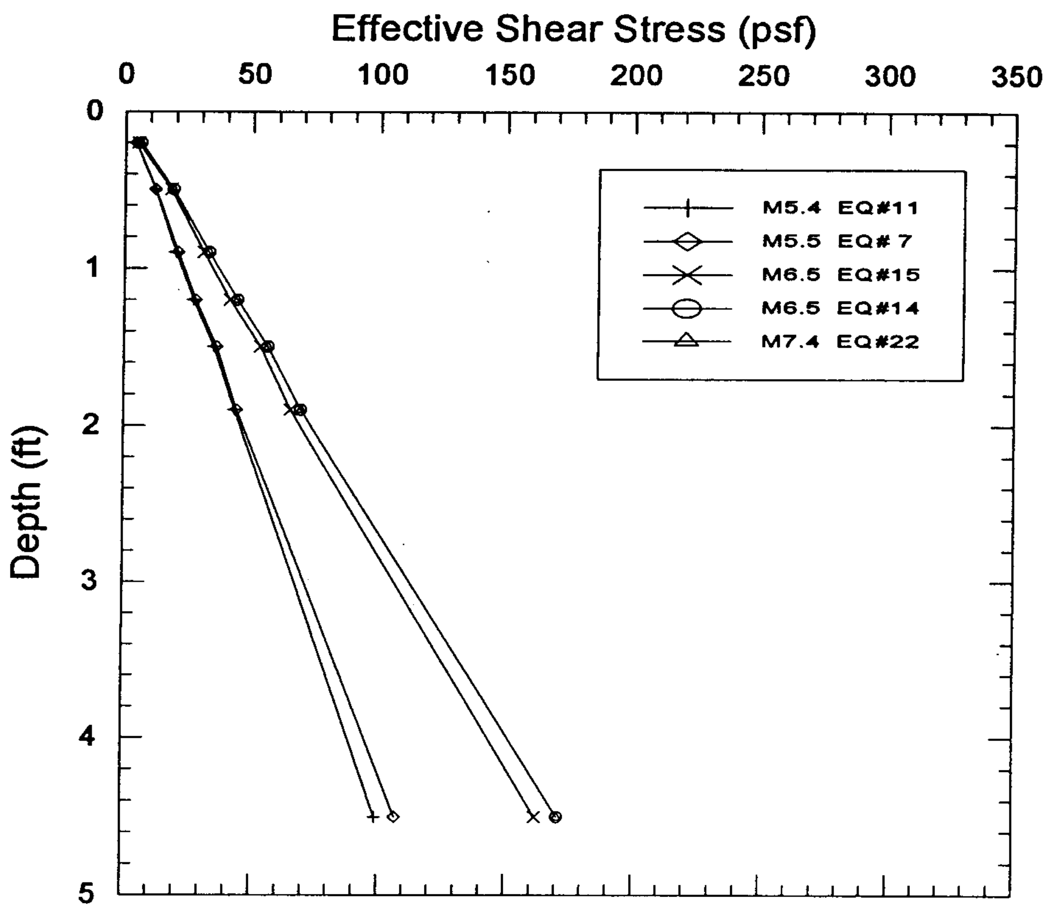


Figure B-4.
Cyclic Shear Stresses
WESHAKE Calculations
0-ft sand cap
75 ft. marine sediments
Rock V_s = 3000 fps

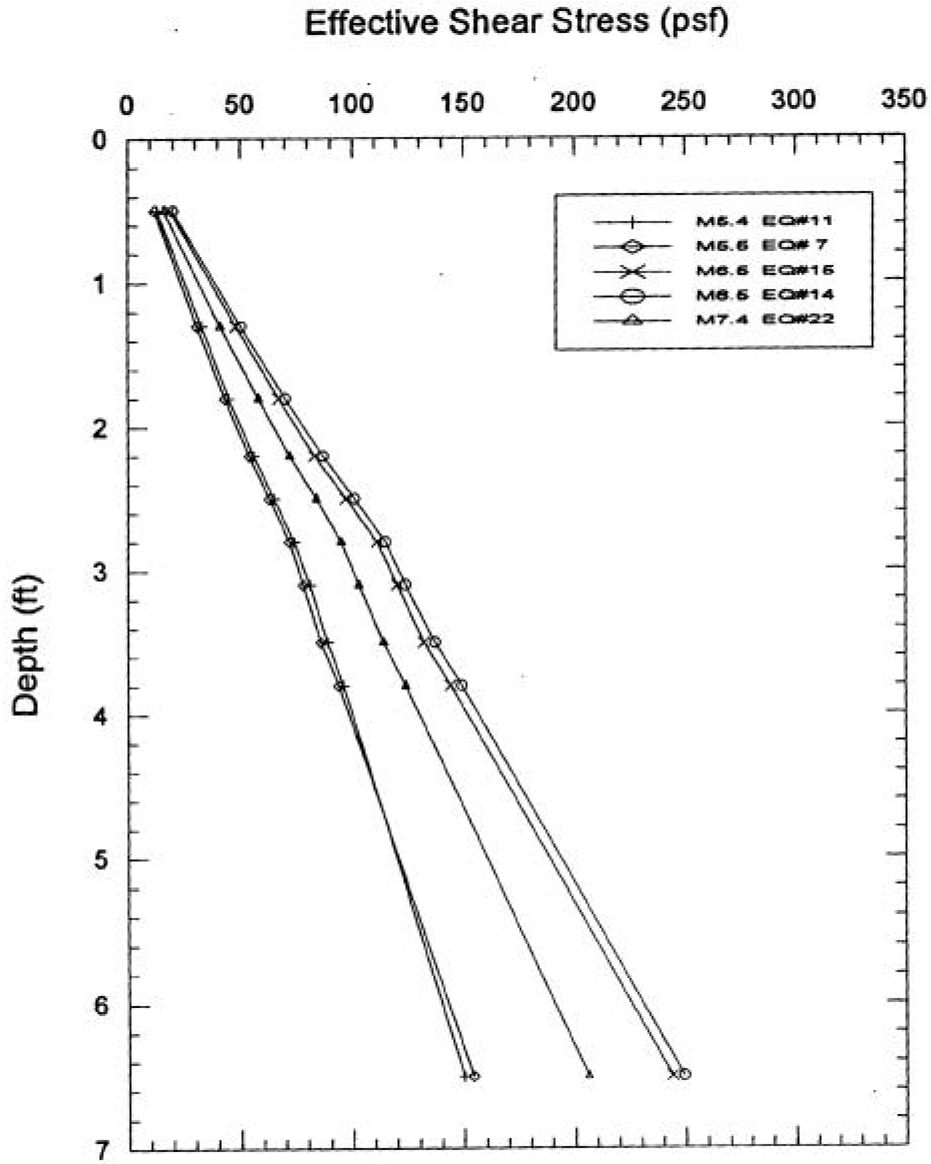


Figure B-5.
Cyclic Shear Stresses
WESHAKE Calculations
2-ft sand cap
75 ft. marine sediments
Rock V_s = 3000 fps

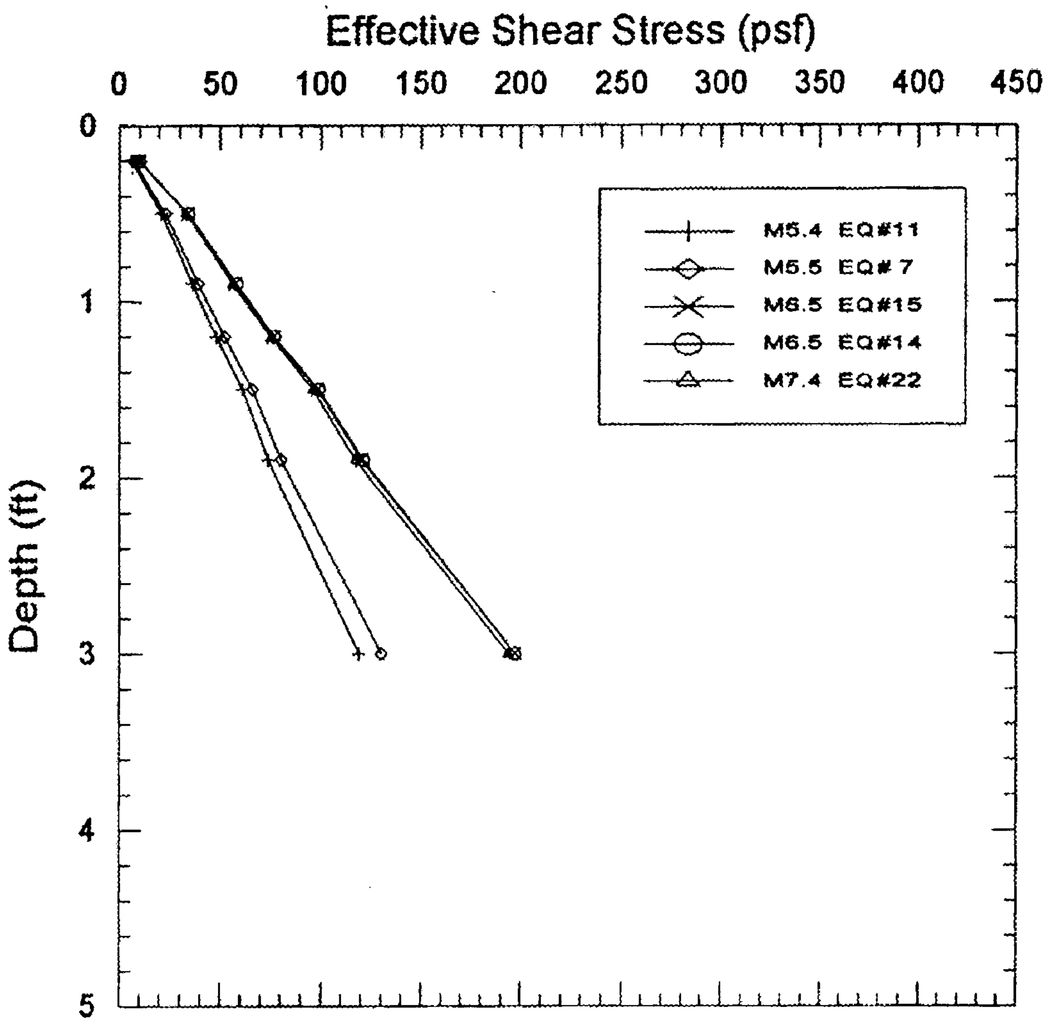


Figure B-6.
Cyclic Shear Stresses
WESHAKE Calculations
0-ft sand cap
30 ft. marine sediments
Rock V_s = 5000 fps

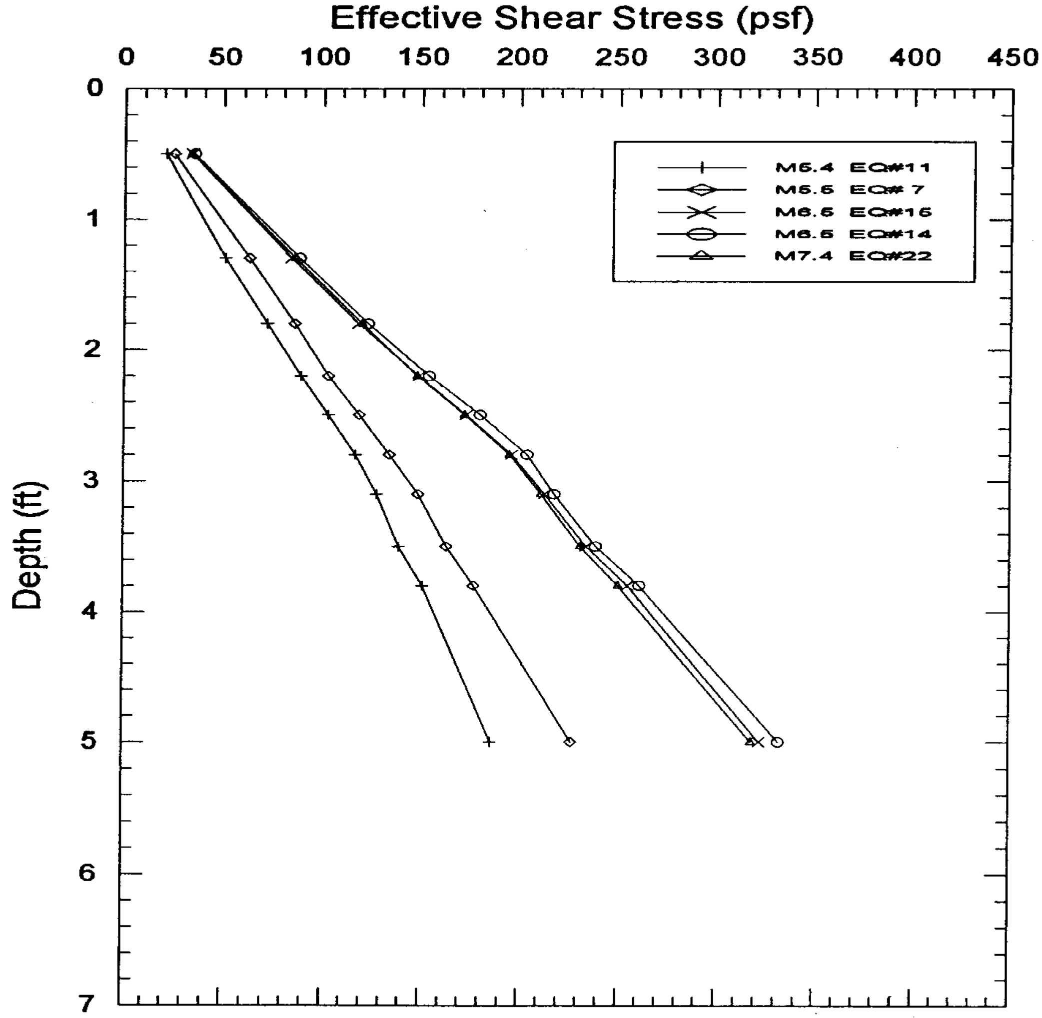


Figure B-7.
Cyclic Shear Stresses
WESHAKE Calculations
2-ft. sand cap
30 ft marine sediments
Rock V_s=3000 fps

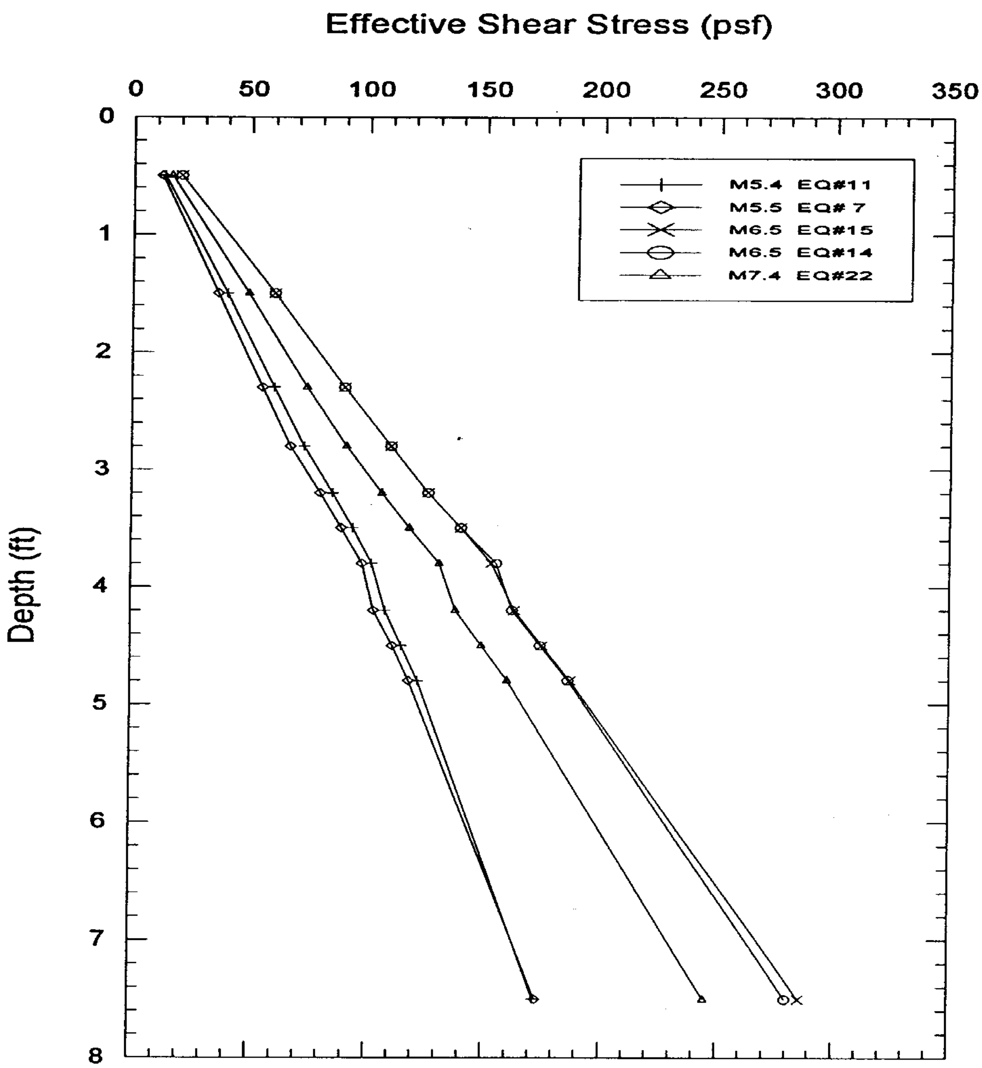


Figure B-8.
Cyclic Shear Stresses
WESHAKE Calculations
3-ft. sand cap
75 ft marine sediments
Rock V_s=3000 fps

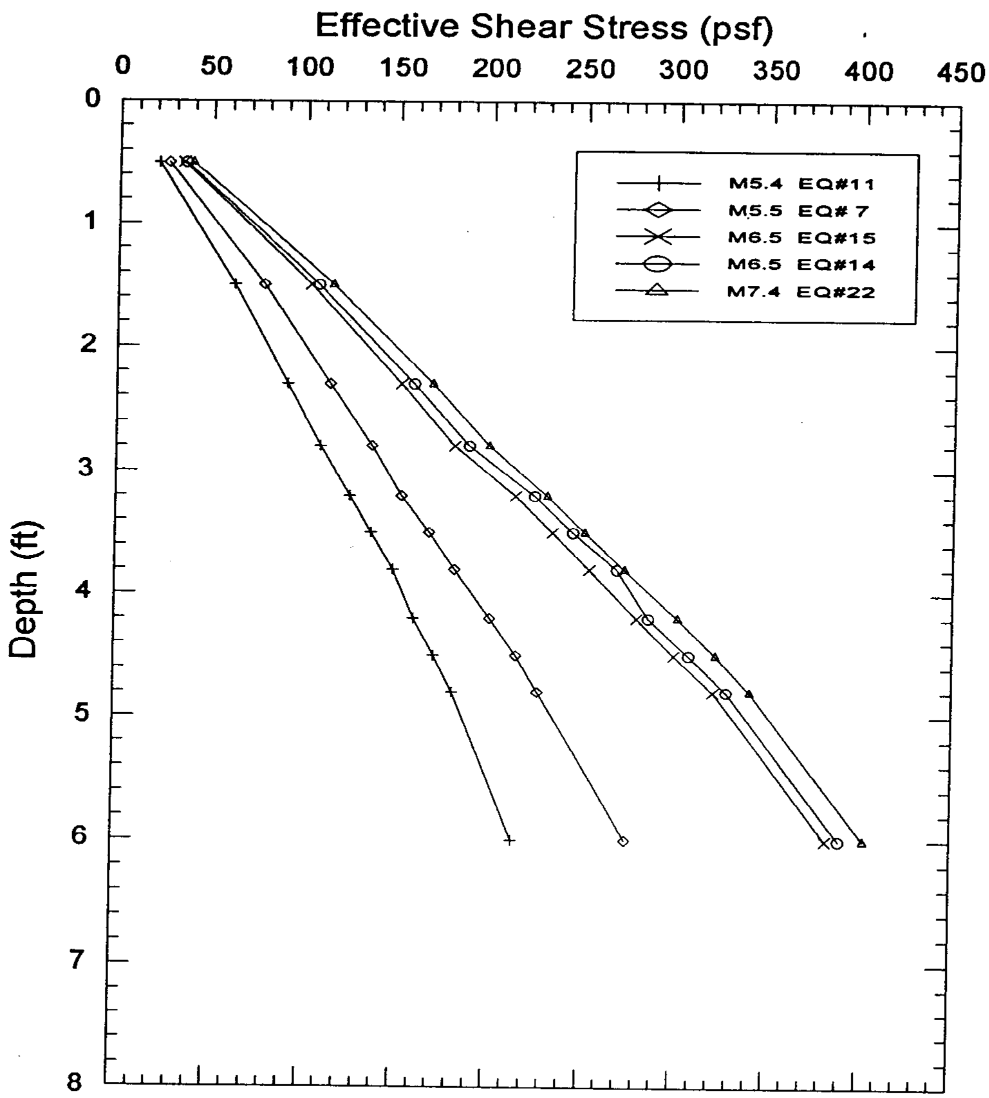


Figure B-9.
Cyclic Shear Stresses
WESHAKE Calculations
3-ft. sand cap
30 ft marine sediments
Rock V_s= 3000 fps

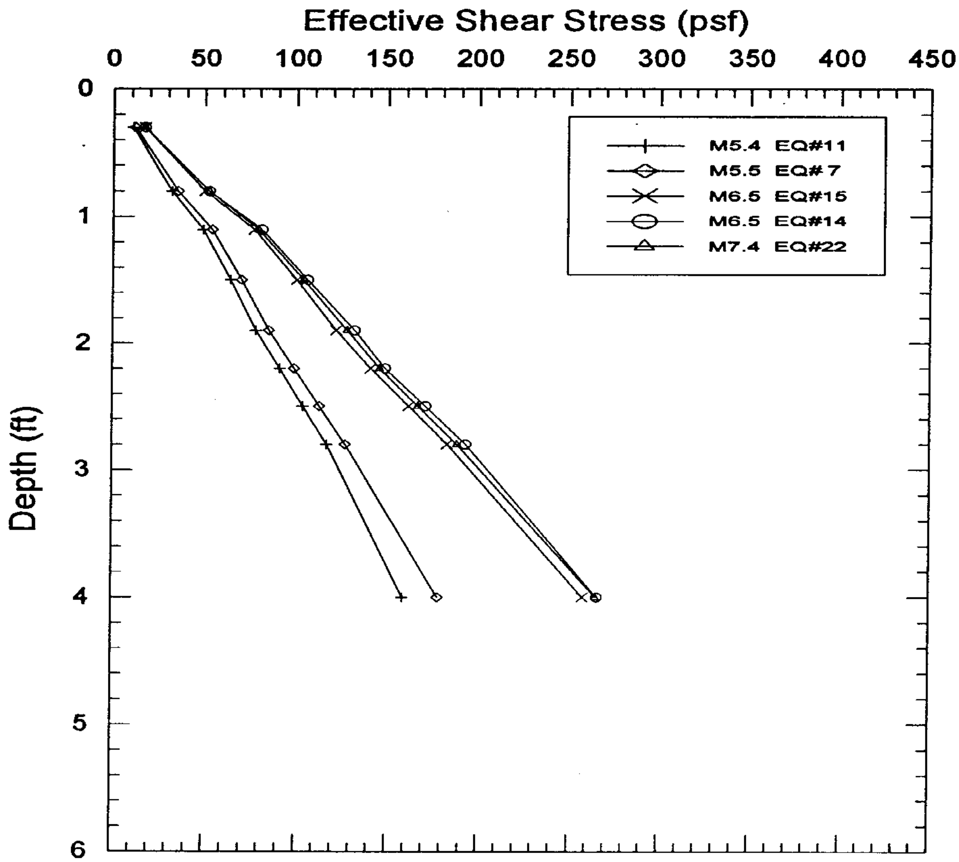


Figure B-10.
Cyclic Shear Stresses
WESHAKE Calculations
1-ft. sand cap
30 ft marine sediments
Rock V_s=3000 fps

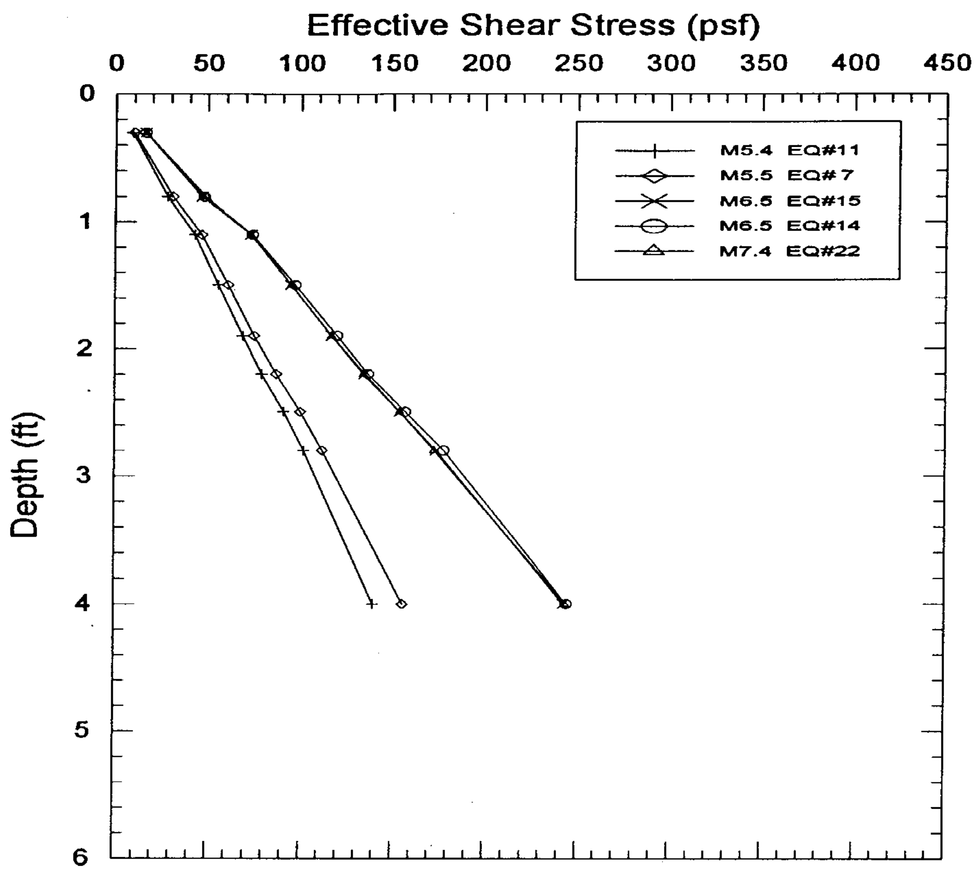


Figure B-11.
Cyclic Shear Stresses
WESHAKE Calculations
1-ft sand cap
30 ft. marine sediments
Rock V_s = 5000 fps

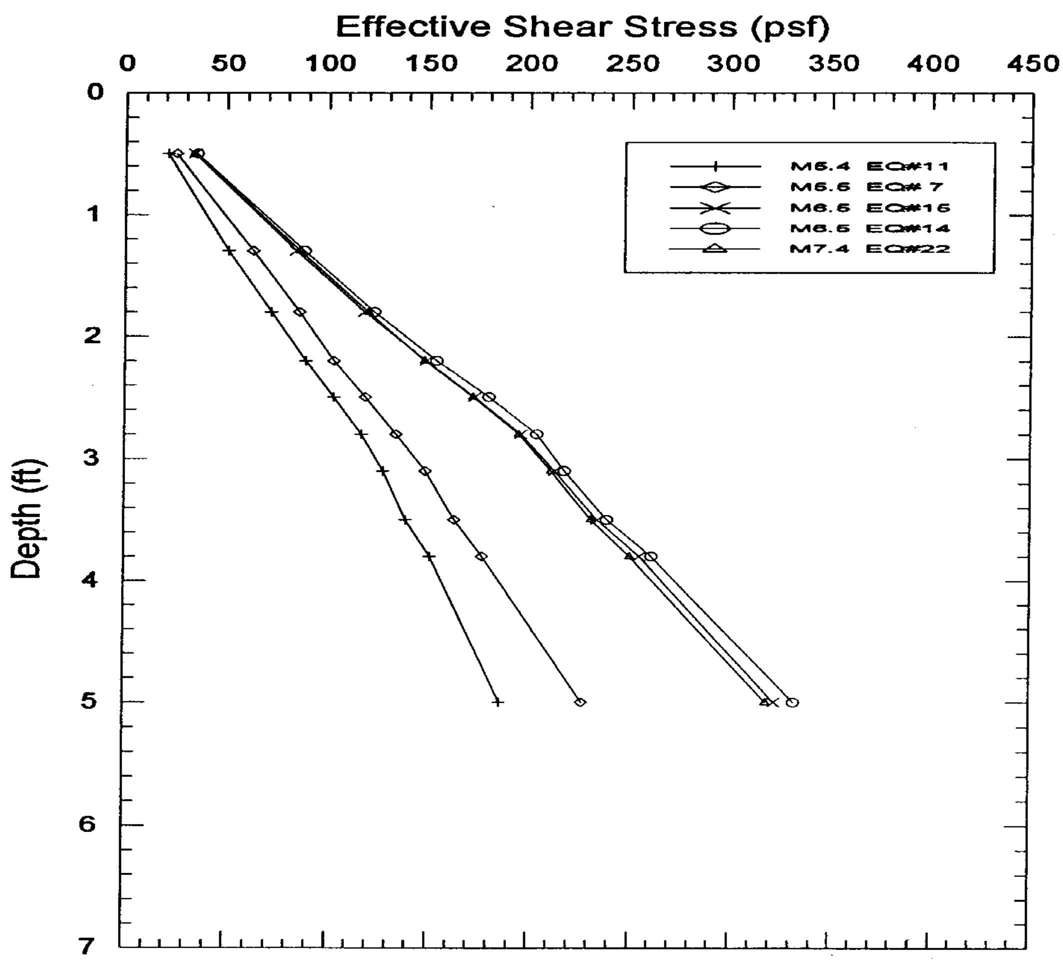


Figure B-12.
Cyclic Shear Stresses
WESHAKE Calculations
2-ft sand cap
30 ft marine sediments
Rock V_s= 3000 fps

Appendix C - Consolidation Analysis

The U.S. Army Engineer Waterways Experiment Station (WES) is currently evaluating options for in situ capping for Palos Verdes (PV) shelf contaminated sediments. This appendix describes one aspect of the study, an evaluation of consolidation of contaminated sediment following cap placement.

The analysis of the consolidation of the effluent-affected (EA) sediment deposit was performed to support the contaminant flux analysis. The EA sediment is compressible, and the placement of a cap layer will cause consolidation to occur. As consolidation progresses, pore water from the EA sediment will be expelled upward into the cap. This advected pore water will contain some concentration of DDT and PCB. Computation of the volume of pore water expelled is needed for the contaminant flux calculations and to estimate the thickness of cap required to retain this volume.

In considering the potential contaminant flux, the advection of pore water would be expected to occur largely within a matter of weeks to months following cap placement. The resulting redistribution of contaminants would therefore serve as a new “starting point” for long term calculations of flux due to diffusion. The thickness of the EA sediment layer varies from a few cm to a maximum of about 60 cm. The maximum thickness is comparable to the range of capping layer thicknesses (15 to 45 cm) evaluated at this time. Further, the compressibility of the EA sediments varies from low to moderate as compared to fine-grained dredged sediments (see following discussion). Therefore the anticipated magnitude of consolidation was not expected to be large in comparison with the layer thickness, and the volume of pore water expelled was therefore expected to be easily retained within the cap layer (i.e., would not flow through the entire cap layer thickness).

The physical properties of the EA sediments indicate that consolidation would occur over a period of weeks following cap placement. For these reasons, the major focus of this preliminary analysis was on the magnitude of consolidation, and not on the rate of consolidation. Further, because of the relatively small thickness of the layers, a straight-forward and conservative estimate of the magnitude of consolidation was deemed appropriate. Both the magnitude of consolidation resulting from placement of various thickness of cap and the thickness of the cap layer into which the expelled pore water travels were determined for this analysis.

Sediment Characterization

The EA sediment deposit has been characterized by the U.S. Geological Survey (USGS) (Lee 1994). The USGS study included data collected at a number of stations on the shelf. The magnitude of consolidation of the EA sediments was calculated for each of the USGS stations and considered the specific layering and sediment properties present at each station.

Capping sediments would potentially be acquired from several sources. As discussed in Chapter 3, characterization data for the Queen's Gate dredging project were considered representative of sediments which would be removed from the harbor in future years and were used for this analysis. This material is composed of approximately 50% sand, 40% silt, and 10% clay. Direct release from hopper dredges is the suggested placement method for the cap material. The water depths at the site and the method of release would result in the material settling through the water column and a gradual buildup of the cap due to multiple releases from the hopper dredge. The cap would undergo consolidation within a time frame of weeks following initial placement. The initial void ratio of the cap material was conservatively assumed to be 0.95 for this analysis for purposes of computing loadings due to cap placement.

Consolidation Testing

The USGS had previously conducted consolidation tests on the EA sediments, and data from these tests were used for this consolidation analysis. These tests were conducted as a part of an evaluation of the stability of the EA deposit (Lee and McArthur in preparation). The USGS conducted 13 constant rate of strain (CRS) consolidation tests on samples obtained from 7 borings taken along LACSD transect 6, through the middle of the EA deposit.

Consolidation test data are normally displayed as a plot of the sample void ratio versus the log of the effective stress. Such e-log P plots are used in calculating the change in void ratio due to a change in effective stress resulting from a loading such as placement of a cap layer. The e-log P curves from the CRS consolidation tests are shown plotted in Figure C1. The coefficients of consolidation (the slopes of the lower portions of the curves) are indicative of the relative compressibility of the samples and vary with the total organic content (TOC) and initial water content (or void ratio) of the samples. For this analysis, a regression line was fitted to the CRS e-log P data for ease in computing consolidation. These relationships are shown plotted in the Figure C2. The relationships for coefficient of consolidation versus sediment TOC and initial void ratio are shown plotted in Figures C3 and C4. These relationships clearly indicate that the compressibility of the sediments varies with these sediment properties, and that a given e-log P curve for calculation of consolidation could be selected based on these sediment properties.

Calculation of Consolidation

The magnitude of consolidation at a given station was computed as follows:

1. Sublayers were determined for the analysis based on logical breaks in the sediment TOC, PCB, DDT, and density (see Chapter 2).
2. Average initial density of each sublayer prior to cap placement was calculated considering the densities of all 2-cm increments in the USGS data set for that sublayer.
3. Average initial effective stress was calculated for each sublayer.
4. An initial condition was plotted on the family of fitted e-log P curves.
5. An e-log P curve was selected for each sublayer based on the initial void ratio of the sublayer. The curve lying immediately below the plotted initial condition was used as opposed to the curve nearest the plotted initial condition (this would give a conservative estimate of the magnitude of consolidation).
6. Increased effective stress for each sublayer was calculated based on the applied cap layer thickness.
7. A new void ratio value for each sublayer was determined from the selected e-log P curves.
8. Change in thickness (consolidation) for each sublayer was computed as Delta t = Delta e/ $(1+e_o)$.

Consolidation values were calculated for each USGS station for a range of applied capping thicknesses using a Microsoft Excel spreadsheet. The results for applied cap thicknesses of 15 and 45 cm and are shown in shown in Tables C1 and C2. These results were used in the chemical isolation evaluation as described in Chapter 3.

Summary of Results

The consolidation of the EA layer is proportional to the applied cap thickness and the thickness of the compressible EA layer (see plot for the station with greatest EA layer thickness in Chapter 3). The calculated changes in thickness for all stations indicate that the EA layer will consolidate on the order of 10% of its thickness due to placement of a 45 cm (1.5 ft) cap. Results for other applied cap thicknesses would be proportional. The maximum computed change in thickness for a 45 cm cap was about 9 cm (about 3 inches). The cap thickness occupied by the expelled water was also calculated, and the maximum thickness occupied by this maximum compression is approximately 18 cm (about 7 inches). Therefore, the water expelled by consolidation will easily remain within the cap thickness as placed.

References

Lee, H.J. (1994). "The distribution and character of contaminated effluent-affected sediment, Palos Verdes Margin, Southern California," Expert Report.

Lee, H.J. and McAuther, W.G. (In preparation). “Stability of sediment on the Palos Verdes Margin, Southern California,” Report prepared by the U.S. Geological Survey for the Los Angeles County Sanitation Districts.

Table C1
Consolidation computations for a 15 cm cap

Using 0.5ft of cap material

Station	Core #	Dry Dens. ρδ (g/cc)	Void Ratio [eo]	Thickness (m)	Volume of solids Vs=t/(1+eo) (m3)	Ave. layer eff. weight We=(SG-1)*gw*Vs (KN)	Ave. initial eff. stress (KPa)	Ave. final eff. stress (KPa)	Curve number	eavg (from reg)	Porosity (n) n=e/(1+e)	Change in e De (m)	Change in thick. Dt=(to*De)/(1+eo) (m)	Change in total thickness (m)	Advetion thickness (m)
(1.5ft)	Cap	1.359	0.95	0.45	0.230769231	3.735346154									
(0.5ft)		1.359	0.95	0.15	0.076923077	1.245115385									
(1ft)		1.359	0.95	0.3048	0.156307692	2.530074462									
514	160-B1	0.980	1.70408163	0.16	0.059169811	0.957752151	0.478876075	1.72399146	FOUND	1.527	0.630188679	-0.177052989	-0.010476192		
		0.940	1.81914894	0.08	0.028377358	0.459330113	1.187417208	2.43253259	FOUND	1.819	0.645283019	0	0		
		1.240	1.13709677	0.08	0.037433962	0.60592483	1.720044679	2.96516006	FOUND	1.137	0.532075472	0	0		
		0.470	4.63829787	0.04	0.00709434	0.114832528	2.080423358	3.32553874	E2	3.821	0.822641509	-0.816868379	-0.005795142	**-0.016271334**	**0.033399053**
516	166-B1	0.990	1.67676768	0.04	0.014943396	0.241881283	0.120940642	1.36605603	FOUND	1.677	0.626415094	0	0		
		1.190	1.22689076	0.04	0.017962264	0.290746189	0.387254377	1.63236976	FOUND	1.227	0.550943396	0	0		
		1.210	1.19008264	0.04	0.018264151	0.295632679	0.680443811	1.9255592	FOUND	1.190	0.543396226	0	0	**0**	**0**
518	106-B1	0.710	2.73239437	0.08	0.021433962	0.34694083	0.173470415	1.4185858	E11	2.206	0.732075472	-0.52661094	-0.011287359		
		1.320	1.00757576	0.04	0.019924528	0.322508377	0.508195019	1.7533104	FOUND	1.008	0.501886792	0	0	**-0.011287359**	**0.02316879**
519	159-B1	0.750	2.53333333	0.04	0.011320755	0.183243396	0.091621698	1.33673708	E8	1.885	0.716981132	-0.648446789	-0.007340907		
		0.810	2.27160494	0.04	0.012226415	0.197902868	0.28219483	1.52731021	E8	1.867	0.694339623	-0.404817346	-0.004949465		
		1.035	1.56038647	0.08	0.031245283	0.505751774	0.634022151	1.87913754	FOUND	1.560	0.609433962	0	0	**-0.012290372**	**0.025227606**
522	124-B1	0.927	1.85868393	0.3	0.104943396	1.698666283	0.849333142	2.09444853	FOUND	1.505	0.650188679	-0.353767303	-0.037125542		
		1.055	1.51184834	0.08	0.031849057	0.515524755	1.95642866	3.20154404	FOUND	1.457	0.601886792	-0.055137074	-0.001756064		
		1.288	1.05745342	0.1	0.048603774	0.786724981	2.607553528	3.85266891	FOUND	1.057	0.513962264	0	0	**-0.038881606**	**0.079809612**
523	108-B2	0.757	2.5006605	0.06	0.017139623	0.277430502	0.138715251	1.38383064	E8	1.880	0.714339623	-0.620475876	-0.010634722		
		1.123	1.35975067	0.06	0.025426415	0.411564668	0.483212836	1.72832822	FOUND	1.360	0.576226415	0	0		
		1.377	0.92447349	0.06	0.031177358	0.504652313	0.941321326	2.18643671	FOUND	0.924	0.480377358	0	0	**-0.010634722**	**0.021829167**
524	102-B1	0.985	1.69035533	0.08	0.029735849	0.481319321	0.24065966	1.48577504	FOUND	1.690	0.628301887	0	0		
		1.18	1.24576271	0.08	0.035622642	0.576605887	0.769622264	2.01473765	FOUND	1.246	0.554716981	0	0	**0**	**0**
525	156-B1	0.545	3.86238532	0.04	0.008226415	0.133156868	0.066578434	1.31169382	E1	2.640	0.794339623	-1.222099619	-0.010053499	**-7.95233E-05**	**0.000163232**
532	148-B1	0.647	3.09582689	0.16	0.039064151	0.632311879	0.31615594	1.56127132	E1	2.599	0.755849057	-0.496508597	-0.019395687		
		0.810	2.27160494	0.08	0.02445283	0.395805736	0.830214747	2.07533013	E11	2.135	0.694339623	-0.136891399	-0.003347382		
		1.290	1.05426357	0.08	0.038943396	0.630357283	1.343296257	2.58841164	FOUND	1.054	0.513207547	0	0	**-0.022743069**	**0.046683141**
533	149-B1	0.590	3.49152542	0.16	0.035622642	0.576605887	0.288302943	1.53341833	E10	3.056	0.777358491	-0.435247272	-0.015504658		
		0.715	2.70629371	0.08	0.021584906	0.349384075	0.751297925	1.99641331	E11	2.142	0.730188679	-0.564338302	-0.012181189		
		1.243	1.13193886	0.12	0.056286792	0.911086166	1.381533045	2.62664843	FOUND	1.132	0.530943396	0	0	**-0.027685847**	**0.056828843**

Cap e	**0.95**
S.G.	**2.65**
Unit weight of water gw(KN/m3)	**9.81**
Area(m2)	**1**

Table C1
Consolidation computations for a 15 cm cap

Using 0.5ft of cap material

Station	Core #	Dry Dens. ρδ (g/cc)	Void Ratio [eo]	Thickness (m)	Volume of solids Vs=t/(1+eo) (m3)	Ave. layer eff. weight We=(SG-1)*gw*Vs (KN)	Ave. initial eff. stress (KPa)	Ave. final eff. stress (KPa)	Curve number	eavg (from reg)	Porosity (n) n=e/(1+e)	Change in e De (m)	Change in thick. Dt=(to*De)/(1+eo) (m)	Change in total thickness (m)	Advetion thickness (m)
534	173-B1	1.032	1.56782946	0.52	0.20250566	3.277857872	1.638928936	2.88404432	FOUND	1.469	0.610566038	-0.099253849	-0.020099466	**-0.0026778**	**0.005496536**
536	174-B1	0.768	2.45052083	0.2	0.057962264	0.938206189	0.469103094	1.71421848	E11	2.170	0.710188679	-0.280098053	-0.016235117		
		0.680	2.89705882	0.16	0.041056604	0.664562717	1.270487547	2.51560293	E1	2.487	0.743396226	-0.409933766	-0.016830488		
		1.365	0.94139194	0.08	0.041207547	0.667005962	1.936271887	3.18138727	FOUND	0.941	0.48490566	0	0	**-0.033065606**	**0.067871506**
539	111-B1	0.908	1.9185022	0.52	0.178173585	2.884006732	1.442003366	2.68711875	E8	1.790	0.657358491	-0.128436364	-0.022883967		
		0.890	1.97752809	0.08	0.026867925	0.43489766	3.101455562	4.34657095	E8	1.725	0.664150943	-0.252770878	-0.006791429	**-0.029675396**	**0.060912655**
542	113-B1	1.005	1.63681592	0.08	0.030339623	0.491092302	0.245546151	1.49066154	FOUND	1.637	0.620754717	0	0		
		1.220	1.17213115	0.12	0.055245283	0.894227774	0.938206189	2.18332157	FOUND	1.172	0.539622642	0	0	**0**	**0**
543	114-B1	0.670	2.95522388	0.04	0.010113208	0.163697434	0.081848717	1.3269641	E11	2.218	0.747169811	-0.736968424	-0.007453115		
		0.890	1.97752809	0.12	0.040301887	0.652346491	0.489870679	1.73498606	FOUND	1.526	0.664150943	-0.45122162	-0.018185083	**-0.025638197**	**0.052625773**
544	115-B2	0.555	3.77477477	0.08	0.016754717	0.271200226	0.135600113	1.3807155	E10	3.085	0.790566038	-0.689880557	-0.011558753	**-0.000179318**	**0.000368074**
547	143-B1	1.305	1.03065134	0.16	0.078792453	1.275374038	0.637687019	1.8828024	FOUND	1.031	0.50754717	0	0		
		1.492	0.77613941	0.16	0.090083019	1.458128785	2.00443843	3.24955381	FOUND	0.776	0.436981132	0	0	**0**	**0**
550	169-B1	0.634	3.17981073	0.26	0.062203774	1.006861381	0.503430691	1.74854608	E1	2.573	0.760754717	-0.60713687	-0.037766204		
		0.512	4.17578125	0.08	0.015456604	0.250188317	1.13195554	2.37707092	E12	3.397	0.806792453	-0.779029301	-0.012041147		
		0.732	2.62021858	0.12	0.03314717	0.536536664	1.52531803	2.77043341	E1	2.464	0.723773585	-0.155788267	-0.00516394	**-0.054971292**	**0.112835809**
552	146-B1	0.500	4.3	0.08	0.01509434	0.244324528	0.122162264	1.36727765	E10	3.088	0.811320755	-1.212437745	-0.018300947		
		0.630	3.20634921	0.08	0.019018868	0.307848906	0.398248981	1.64336437	E1	2.587	0.762264151	-0.619083767	-0.011774272		
		1.04	1.54807692	0.08	0.031396226	0.508195019	0.806270943	2.05138633	FOUND	1.548	0.60754717	0	0	**-0.030075219**	**0.061733345**
553	130-B1	0.855	2.0994152	0.08	0.025811321	0.417794943	0.208897472	1.45401286	FOUND	1.546	0.677358491	-0.553038777	-0.014274661		
		1.185	1.23628692	0.08	0.035773585	0.579049132	0.707319509	1.95243489	FOUND	1.236	0.552830189	0	0	**-0.014274661**	**0.02930062**
554	125-B2	0.655	3.04580153	0.04	0.009886792	0.160032566	0.080016283	1.32513167	E11	2.219	0.752830189	-0.827287936	-0.008179224		
		1.377	0.92447349	0.06	0.031177358	0.504652313	0.412358723	1.65747411	FOUND	0.924	0.480377358	0	0		
		1.588	0.66876574	0.22	0.131833962	2.13393043	1.731650094	2.97676548	FOUND	0.669	0.400754717	0	0		
		1.025	1.58536585	0.07	0.027075472	0.438257123	3.017743871	4.26285926	FOUND	1.424	0.613207547	-0.161179051	-0.004363999	**-0.012543223**	**0.025746616**
555	132-B1	1.123	1.35975067	0.4	0.169509434	2.743764453	1.371882226	2.61699761	FOUND	1.360	0.576226415	0	0	**0**	**0**

Table C1
Consolidation computations for a 15 cm cap

Using 0.5ft of cap material

Station	Core #	Dry Dens. ρδ (g/cc)	Void Ratio [eo]	Thickness (m)	Volume of solids Vs=t/(1+eo) (m3)	Ave. layer eff. weight We=(SG-1)*gw*Vs (KN)	Ave. initial eff. stress (KPa)	Ave. final eff. stress (KPa)	Curve number	eavg (from reg)	Porosity (n) n=e/(1+e)	Change in e De (m)	Change in thick. Dt=(to*De)/(1+eo) (m)	Change in total thickness (m)	Advetion thickness (m)
556	147-B3	0.669	2.96113602	0.22	0.055539623	0.898992102	0.449496051	1.69461144	E1	2.580	0.74754717	-0.381093081	-0.021165766		
		0.609	3.35139573	0.16	0.036769811	0.595174551	1.196579377	2.44169476	E10	2.929	0.770188679	-0.42202221	-0.015517677		
		0.550	3.81818182	0.08	0.016603774	0.268756981	1.628545143	2.87366053	E12	3.330	0.79245283	-0.487698239	-0.008097631	**-0.044781074**	**0.091919047**
557	127-B1	0.483	4.48654244	0.14	0.025516981	0.413030615	0.206515308	1.45163069	E12	3.569	0.817735849	-0.917522201	-0.023412397		
		0.476	4.56722689	0.16	0.028739623	0.465193902	0.645627566	1.89074295	E12	3.477	0.820377358	-1.090520458	-0.031341146		
		0.807	2.28376704	0.08	0.024362264	0.394339789	1.075394411	2.3205098	E8	1.810	0.695471698	-0.4737817	-0.011542395	**-0.066295938**	**0.136081136**
559	136-B1	0.445	4.95505618	0.04	0.006716981	0.108724415	0.054362208	1.29947759	E12	3.608	0.832075472	-1.347359622	-0.009050189		
		0.490	4.40816327	0.02	0.003698113	0.059859509	0.13865417	1.38376955	E12	3.586	0.81509434	-0.822419865	-0.003041402		
		0.550	3.81818182	0.08	0.016603774	0.268756981	0.302962415	1.5480778	E10	3.054	0.79245283	-0.764499246	-0.012693572		
		0.795	2.33333333	0.04	0.012	0.194238	0.534459906	1.77957529	E8	1.846	0.7	-0.487305022	-0.00584766		
		0.840	2.1547619	0.02	0.006339623	0.102616302	0.682887057	1.92800244	E8	1.835	0.683018868	-0.319612495	-0.002026223	**-0.032659046**	**0.06703699**
563	128-B1	1.416	0.87146893	0.32	0.170988679	2.767708257	1.383854128	2.62896951	FOUND	0.871	0.465660377	0	0	**0**	**0**
564	171-B1	0.650	3.07692308	0.02	0.00490566	0.079405472	0.039702736	1.28481812	E1	2.645	0.754716981	-0.431768235	-0.002118108		
		0.711	2.72714487	0.18	0.04829434	0.781716328	0.470263636	1.71537902	E11	2.170	0.731698113	-0.556848509	-0.026892631		
		0.558	3.74910394	0.1	0.021056604	0.340832717	1.031538158	2.27665354	E12	3.412	0.789433962	-0.337275365	-0.007101874		
		0.476	4.56722689	0.1	0.017962264	0.290746189	1.347327611	2.592443	E2	3.933	0.820377358	-0.634306212	-0.011393576	**-0.047506189**	**0.097512703**
566	122-B1	0.550	3.81818182	0.04	0.008301887	0.134378491	0.067189245	1.31230463	E1	2.640	0.79245283	-1.178005615	-0.009779669		
		0.660	3.01515152	0.04	0.009962264	0.161254189	0.215005585	1.46012097	E11	2.200	0.750943396	-0.814758918	-0.008116844		
		1.350	0.96296296	0.16	0.081509434	1.319352453	0.955308906	2.20042429	FOUND	0.963	0.490566038	0	0	**-0.017896513**	**0.036734947**
570	121-B1	0.627	3.22647528	0.12	0.028392453	0.459574438	0.229787219	1.4749026	E1	2.613	0.763396226	-0.613772107	-0.017426496		
		0.742	2.57142857	0.16	0.0448	0.7251552	0.822152038	2.06726742	E11	2.135	0.72	-0.435987896	-0.019532258		
		1.290	1.05426357	0.08	0.038943396	0.630357283	1.499908279	2.74502366	FOUND	1.054	0.513207547	0	0	**-0.036958753**	**0.075862704**
571	177-B4	0.620	3.27419355	0.04	0.009358491	0.151481208	0.075740604	1.32085599	E11	2.219	0.766037736	-1.055076253	-0.009873921		
		0.650	3.07692308	0.04	0.009811321	0.158810943	0.230886679	1.47600206	E11	2.198	0.754716981	-0.878551252	-0.008619748		
		0.980	1.70408163	0.04	0.014792453	0.239438038	0.43001117	1.67512655	FOUND	1.530	0.630188679	-0.173786591	-0.00257073		
		1.200	1.20833333	0.04	0.018113208	0.293189434	0.696324906	1.94144029	FOUND	1.208	0.547169811	0	0		
		1.250	1.12	0.04	0.018867925	0.30540566	0.995622453	2.24073784	FOUND	1.120	0.528301887	0	0	**-0.021064399**	**0.043237451**

Table C1
Consolidation computations for a 15 cm cap

Using 0.5ft of cap material

Station	Core #	Dry Dens. ρδ (g/cc)	Void Ratio [eo]	Thickness (m)	Volume of solids Vs=t/(1+eo) (m3)	Ave. layer eff. weight We=(SG-1)*gw*Vs (KN)	Ave. initial eff. stress (KPa)	Ave. final eff. stress (KPa)	Curve number	eavg (from reg)	Porosity (n) n=e/(1+e)	Change in e De (m)	Change in thick. Dt=(to*De)/(1+eo) (m)	Change in total thickness (m)	Advetion thickness (m)
572	155-B2	0.520	4.09615385	0.04	0.007849057	0.127048755	0.063524377	1.30863976	E12	3.605	0.803773585	-0.490911441	-0.003853192		
		0.473	4.602537	0.04	0.007139623	0.115565502	0.184831506	1.42994689	E12	3.574	0.821509434	-1.028259708	-0.007341386		
		0.525	4.04761905	0.04	0.007924528	0.128270377	0.306749445	1.55186483	E10	3.053	0.801886792	-0.994603006	-0.00788176		
		0.620	3.27419355	0.04	0.009358491	0.151481208	0.446625238	1.69174062	E1	2.580	0.766037736	-0.693751819	-0.00649247		
		0.870	2.04597701	0.04	0.013132075	0.21256234	0.628647011	1.8737624	E8	1.839	0.671698113	-0.206952402	-0.002717715		
		1.010	1.62376238	0.04	0.015245283	0.246767774	0.858312068	2.10342745	FOUND	1.504	0.618867925	-0.119331716	-0.001819246	**-0.030105768**	**0.06179605**
574	153-B1	0.800	2.3125	0.04	0.012075472	0.195459623	0.097729811	1.3428452	E8	1.884	0.698113208	-0.428232569	-0.00517111		
		0.635	3.17322835	0.08	0.019169811	0.310292151	0.350605698	1.59572108	E1	2.594	0.760377358	-0.579043357	-0.011100152		
		0.650	3.07692308	0.04	0.009811321	0.158810943	0.585157245	1.83027263	E1	2.562	0.754716981	-0.514993229	-0.005052764		
		0.865	2.06358382	0.08	0.026113208	0.422681434	0.875903434	2.12101882	E8	1.822	0.673584906	-0.241391366	-0.006303503		
		1.280	1.0703125	0.12	0.057962264	0.938206189	1.556347245	2.80146263	FOUND	1.070	0.516981132	0	0	**-0.027627529**	**0.056709138**
577	120-B1	0.900	1.94444444	0.08	0.027169811	0.439784151	0.219892075	1.46500746	FOUND	1.546	0.660377358	-0.398923778	-0.010838684		
		0.900	1.94444444	0.08	0.027169811	0.439784151	0.659676226	1.90479161	FOUND	1.516	0.660377358	-0.428745173	-0.011648925		
		1.413	0.87544232	0.12	0.063984906	1.035691675	1.39741414	2.64252952	FOUND	0.875	0.466792453	0	0	**-0.022487609**	**0.046158777**
581	137-B1	0.657	3.03348554	0.06	0.014875472	0.240781823	0.120390911	1.3655063	E11	2.213	0.752075472	-0.820578461	-0.012206492		
		0.900	1.94444444	0.12	0.040754717	0.659676226	0.570619936	1.81573532	FOUND	1.521	0.660377358	-0.423305768	-0.017251707	**-0.029458198**	**0.060466828**
583	138-B2	0.475	4.57894737	0.08	0.014339623	0.232108302	0.116054151	1.36116954	E2	4.221	0.820754717	-0.357593104	-0.00512775	**-6.80833E-05**	**0.00013975**
584	139-B2	0.575	3.60869565	0.08	0.017358491	0.280973208	0.140486604	1.38560199	E1	2.627	0.783018868	-0.981302532	-0.017033931	**-0.000273781**	**0.000561971**

Table C2
Consolidation computations for a 45 cm cap

Using 1.5ft of cap material

	Station	Core #	Dry Dens. ρδ (g/cc)	Void Ratio [eo]	Thickness (m)	Volume of solids Vs=t/(1+eo) (m3)	Ave. layer eff. weight We=(SG-1)*gw*Vs (KN)	Ave. initial eff. stress (KPa)	Ave. final eff. stress (KPa)	Curve number	eavg (from reg)	Porosity (n) n=e/(1+e)	Change in e De (m)	Change in thick. Dt=(to*De)/(1+eo) (m)	Change in total thickness (m)	Advetion thickness (m)
	(1.5ft)	Cap	1.359	0.95	0.45	0.230769231	3.735346154									
Cap e	(0.5ft)		1.359	0.95	0.15	0.076923077	1.245115385									
0.95	(1ft)		1.359	0.95	0.3048	0.156307692	2.530074462									
	514	160-B1	0.980	1.704081633	0.16	0.059169811	0.957752151	0.478876075	4.214222229	FOUND	1.425	0.630188679	-0.278591262	-0.016484192		
			0.940	1.819148936	0.08	0.028377358	0.459330113	1.187417208	4.922763361	FOUND	1.819	0.645283019	0	0		
S.G.			1.240	1.137096774	0.08	0.037433962	0.60592483	1.720044679	5.455390833	FOUND	1.137	0.532075472	0	0		
2.65			0.470	4.638297872	0.04	0.00709434	0.114832528	2.080423358	5.815769512	E2	3.571	0.822641509	-1.067106453	-0.007570416	**-0.024054608**	**0.04937525**
	516	166-B1	0.990	1.676767677	0.04	0.014943396	0.241881283	0.120940642	3.856286795	FOUND	1.677	0.626415094	0	0		
			1.190	1.226890756	0.04	0.017962264	0.290746189	0.387254377	4.122600531	FOUND	1.227	0.550943396	0	0		
Unit weight of water			1.210	1.190082645	0.04	0.018264151	0.295632679	0.680443811	4.415789965	FOUND	1.190	0.543396226	0	0	**0**	**0**
gw(KN/m3)	518	106-B1	0.710	2.732394366	0.08	0.021433962	0.34694083	0.173470415	3.908816569	E11	2.016	0.732075472	-0.715946601	-0.015345572		
9.81			1.320	1.007575758	0.04	0.019924528	0.322508377	0.508195019	4.243541173	FOUND	1.008	0.501886792	0	0	**-0.015345572**	**0.03149881**
	519	159-B1	0.750	2.533333333	0.04	0.011320755	0.183243396	0.091621698	3.826967852	E8	1.742	0.716981132	-0.79128682	-0.008957964		
			0.810	2.271604938	0.04	0.012226415	0.197902868	0.28219483	4.017540984	E8	1.735	0.694339623	-0.536157927	-0.006555289		
Area(m2)			1.035	1.560386473	0.08	0.031245283	0.505751774	0.634022151	4.369368305	FOUND	1.560	0.609433962	0	0	**-0.015513253**	**0.03184299**
1																
	522	124-B1	0.927	1.858683927	0.3	0.104943396	1.698666283	0.849333142	4.584679295	FOUND	1.416	0.650188679	-0.442764936	-0.046465256		
			1.055	1.511848341	0.08	0.031849057	0.515524755	1.95642866	5.691774814	FOUND	1.391	0.601886792	-0.120501254	-0.003837851		
			1.288	1.057453416	0.1	0.048603774	0.786724981	2.607553528	6.342899682	FOUND	1.057	0.513962264	0	0	**-0.050303107**	**0.10325375**
	523	108-B2	0.757	2.500660502	0.06	0.017139623	0.277430502	0.138715251	3.874061405	E8	1.740	0.714339623	-0.760274906	-0.013030825		
			1.123	1.359750668	0.06	0.025426415	0.411564668	0.483212836	4.21855899	FOUND	1.360	0.576226415	0	0		
			1.377	0.924473493	0.06	0.031177358	0.504652313	0.941321326	4.67666748	FOUND	0.924	0.480377358	0	0	**-0.013030825**	**0.02674748**
	524	102-B1	0.985	1.69035533	0.08	0.029735849	0.481319321	0.24065966	3.976005814	FOUND	1.690	0.628301887	0	0		
			1.18	1.245762712	0.08	0.035622642	0.576605887	0.769622264	4.504968418	FOUND	1.246	0.554716981	0	0	**0**	**0**
	525	156-B1	0.545	3.862385321	0.04	0.008226415	0.133156868	0.066578434	3.801924588	E1	2.390	0.794339623	-1.472396664	-0.012112546	**-9.58104E-05**	**0.00019666**
	532	148-B1	0.647	3.095826893	0.16	0.039064151	0.632311879	0.31615594	4.051502093	E1	2.375	0.755849057	-0.72079232	-0.02815714		
			0.810	2.271604938	0.08	0.02445283	0.395805736	0.830214747	4.565560901	E11	1.987	0.694339623	-0.284168467	-0.006948723		
			1.290	1.054263566	0.08	0.038943396	0.630357283	1.343296257	5.07864241	FOUND	1.054	0.513207547	0	0	**-0.035105863**	**0.0720594**

Table C2
Consolidation computations for a 45 cm cap

Using 1.5ft of cap material

Station	Core #	Dry Dens. $\rho\delta$ (g/cc)	Void Ratio [eo]	Thickness (m)	Volume of solids Vs=t/(1+eo) (m3)	Ave. layer eff. weight We=(SG-1)*gw*Vs (KN)	Ave. initial eff. stress (KPa)	Ave. final eff. stress (KPa)	Curve number	eavg (from reg)	Porosity (n) n=e/(1+e)	Change in e De (m)	Change in thick. Dt=(to*De)/(1+eo) (m)	Change in total thickness (m)	Advetion thickness (m)
533	149-B1	0.590	3.491525424	0.16	0.035622642	0.576605887	0.288302943	4.023649097	E10	2.793	0.777358491	-0.698414645	-0.024879375		
		0.715	2.706293706	0.08	0.021584906	0.349384075	0.751297925	4.486644078	E11	1.991	0.730188679	-0.71560012	-0.015446161		
		1.243	1.131938858	0.12	0.056286792	0.911086166	1.381533045	5.116879199	FOUND	1.132	0.530943396	0	0	**-0.040325536**	**0.08277347**
534	173-B1	1.032	1.567829457	0.52	0.20250566	3.277857872	1.638928936	5.37427509	FOUND	1.398	0.610566038	-0.169961909	-0.034418249	**-0.004585454**	**0.00941225**
536	174-B1	0.768	2.450520833	0.2	0.057962264	0.938206189	0.469103094	4.204449248	E11	2.003	0.710188679	-0.447692404	-0.025949265		
		0.680	2.897058824	0.16	0.041056604	0.664562717	1.270487547	5.005833701	E1	2.325	0.743396226	-0.571772878	-0.023475052		
		1.365	0.941391941	0.08	0.041207547	0.667005962	1.936271887	5.671618041	FOUND	0.941	0.48490566	0	0	**-0.049424318**	**0.10144992**
539	111-B1	0.908	1.918502203	0.52	0.178173585	2.884006732	1.442003366	5.17734952	E8	1.701	0.657358491	-0.217497226	-0.03875226		
		0.890	1.97752809	0.08	0.026867925	0.43489766	3.101455562	6.836801716	E8	1.663	0.664150943	-0.314279151	-0.008444029	**-0.047196289**	**0.09687659**
542	113-B1	1.005	1.63681592	0.08	0.030339623	0.491092302	0.245546151	3.980892305	FOUND	1.637	0.620754717	0	0		
		1.220	1.172131148	0.12	0.055245283	0.894227774	0.938206189	4.673552343	FOUND	1.172	0.539622642	0	0	**0**	**0**
543	114-B1	0.670	2.955223881	0.04	0.010113208	0.163697434	0.081848717	3.817194871	E11	2.021	0.747169811	-0.934345437	-0.009449229		
		0.890	1.97752809	0.12	0.040301887	0.652346491	0.489870679	4.225216833	FOUND	1.425	0.664150943	-0.552333708	-0.022260091	**-0.03170932**	**0.06508755**
544	115-B2	0.555	3.774774775	0.08	0.016754717	0.271200226	0.135600113	3.870946267	E10	2.804	0.790566038	-0.971109299	-0.016270661	**-0.000252417**	**0.00051812**
547	143-B1	1.305	1.030651341	0.16	0.078792453	1.275374038	0.637687019	4.373033173	FOUND	1.031	0.50754717	0	0		
		1.492	0.77613941	0.16	0.090083019	1.458128785	2.00443843	5.739784584	FOUND	0.776	0.436981132	0	0	**0**	**0**
550	169-B1	0.634	3.179810726	0.26	0.062203774	1.006861381	0.503430691	4.238776844	E1	2.364	0.760754717	-0.815404146	-0.050721215		
		0.512	4.17578125	0.08	0.015456604	0.250188317	1.13195554	4.867301693	E12	3.146	0.806792453	-1.029362373	-0.015910446		
		0.732	2.620218579	0.12	0.03314717	0.536536664	1.52531803	5.260664184	E1	2.314	0.723773585	-0.306611094	-0.01016329	**-0.076794951**	**0.15763174**
552	146-B1	0.500	4.3	0.08	0.01509434	0.244324528	0.122162264	3.857508418	E10	2.805	0.811320755	-1.495385862	-0.022571862		
		0.630	3.206349206	0.08	0.019018868	0.307848906	0.398248981	4.133595135	E1	2.370	0.762264151	-0.836032703	-0.015900396		
		1.04	1.548076923	0.08	0.031396226	0.508195019	0.806270943	4.541617097	FOUND	1.548	0.60754717	0	0	**-0.038472258**	**0.07896937**
553	130-B1	0.855	2.099415205	0.08	0.025811321	0.417794943	0.208897472	3.944243626	FOUND	1.433	0.677358491	-0.666403623	-0.017200758		
		1.185	1.23628692	0.08	0.035773585	0.579049132	0.707319509	4.442665663	FOUND	1.236	0.552830189	0	0	**-0.017200758**	**0.03530682**

Table C2
Consolidation computations for a 45 cm cap

Using 1.5ft of cap material

Station	Core #	Dry Dens. ρδ (g/cc)	Void Ratio [eo]	Thickness (m)	Volume of solids Vs=t/(1+eo) (m3)	Ave. layer eff. weight We=(SG-1)*gw*Vs (KN)	Ave. initial eff. stress (KPa)	Ave. final eff. stress (KPa)	Curve number	eavg (from reg)	Porosity (n) n=e/(1+e)	Change in e De (m)	Change in thick. Dt=(to*De)/(1+eo) (m)	Change in total thickness (m)	Advetion thickness (m)
554	125-B2	0.655	3.045801527	0.04	0.009886792	0.160032566	0.080016283	3.815362437	E11	2.021	0.752830189	-1.024833389	-0.010132315		
		1.377	0.924473493	0.06	0.031177358	0.504652313	0.412358723	4.147704876	FOUND	0.924	0.480377358	0	0		
		1.588	0.668765743	0.22	0.131833962	2.13393043	1.731650094	5.466996248	FOUND	0.669	0.400754717	0	0		
		1.025	1.585365854	0.07	0.027075472	0.438257123	3.017743871	6.753090025	FOUND	1.372	0.613207547	-0.213441874	-0.005779039	**-0.015911354**	**0.03266015**
555	132-B1	1.123	1.359750668	0.4	0.169509434	2.743764453	1.371882226	5.10722838	FOUND	1.360	0.576226415	0	0	**0**	**0**
556	147-B3	0.669	2.961136024	0.22	0.055539623	0.898992102	0.449496051	4.184842205	E1	2.367	0.74754717	-0.593717532	-0.032974848		
		0.609	3.351395731	0.16	0.036769811	0.595174551	1.196579377	4.931925531	E10	2.738	0.770188679	-0.613810735	-0.022569705		
		0.550	3.818181818	0.08	0.016603774	0.268756981	1.628545143	5.363891297	E12	3.112	0.79245283	-0.70569743	-0.01171724	**-0.067261793**	**0.13806368**
557	127-B1	0.483	4.486542443	0.14	0.025516981	0.413030615	0.206515308	3.941861461	E12	3.220	0.817735849	-1.266460858	-0.032316258		
		0.476	4.567226891	0.16	0.028739623	0.465193902	0.645627566	4.38097372	E12	3.183	0.820377358	-1.384037655	-0.03977672		
		0.807	2.283767038	0.08	0.024362264	0.394339789	1.075394411	4.810740565	E8	1.711	0.695471698	-0.572788609	-0.013954427	**-0.086047405**	**0.17662362**
559	136-B1	0.445	4.95505618	0.04	0.006716981	0.108724415	0.054362208	3.789708361	E12	3.234	0.832075472	-1.721224751	-0.011561434		
		0.490	4.408163265	0.02	0.003698113	0.059859509	0.13865417	3.874000324	E12	3.226	0.81509434	-1.182015941	-0.004371229		
		0.550	3.818181818	0.08	0.016603774	0.268756981	0.302962415	4.038308569	E10	2.792	0.79245283	-1.026063133	-0.01703652		
		0.795	2.333333333	0.04	0.012	0.194238	0.534459906	4.26980606	E8	1.727	0.7	-0.606156323	-0.007273876		
		0.840	2.154761905	0.02	0.006339623	0.102616302	0.682887057	4.41823321	E8	1.723	0.683018868	-0.432225382	-0.002740146	**-0.042983205**	**0.08822868**
563	128-B1	1.416	0.871468927	0.32	0.170988679	2.767708257	1.383854128	5.119200282	FOUND		0.465660377	-0.871468927	-0.149011321	**-0.019302461**	**0.03962084**
564	171-B1	0.650	3.076923077	0.02	0.00490566	0.079405472	0.039702736	3.77504889	E1	2.392	0.754716981	-0.685265893	-0.003361682		
		0.711	2.727144866	0.18	0.04829434	0.781716328	0.470263636	4.20560979	E11	2.003	0.731698113	-0.724367991	-0.034982874		
		0.558	3.749103943	0.1	0.021056604	0.340832717	1.031538158	4.766884312	E12	3.154	0.789433962	-0.595403275	-0.012537171		
		0.476	4.567226891	0.1	0.017962264	0.290746189	1.347327611	5.082673765	E2	3.632	0.820377358	-0.935714319	-0.016807548	**-0.067689274**	**0.13894114**
566	122B-1	0.550	3.818181818	0.04	0.008301887	0.134378491	0.067189245	3.802535399	E1	2.390	0.79245283	-1.428230945	-0.011857012		
		0.660	3.015151515	0.04	0.009962264	0.161254189	0.215005585	3.950351739	E11	2.014	0.750943396	-1.000678219	-0.009969021		
		1.350	0.962962963	0.16	0.081509434	1.319352453	0.955308906	4.69065506	FOUND	0.963	0.490566038	0	0	**-0.021826032**	**0.0448008**
570	121-B1	0.627	3.226475279	0.12	0.028392453	0.459574438	0.229787219	3.965133373	E1	2.380	0.763396226	-0.846372568	-0.024030593		
		0.742	2.571428571	0.16	0.0448	0.7251552	0.822152038	4.557498192	E11	1.988	0.72	-0.583661923	-0.026148054		
		1.290	1.054263566	0.08	0.038943396	0.630357283	1.499908279	5.235254433	FOUND	1.054	0.513207547	0	0	**-0.050178647**	**0.10299828**

Table C2
Consolidation computations for a 45 cm cap

Using 1.5ft of cap material

Station	Core #	Dry Dens. ρδ (g/cc)	Void Ratio [eo]	Thickness (m)	Volume of solids Vs=t/(1+eo) (m3)	Ave. layer eff. weight We=(SG-1)*gw*Vs (KN)	Ave. initial eff. stress (KPa)	Ave. final eff. stress (KPa)	Curve number	eavg (from reg)	Porosity (n) n=e/(1+e)	Change in e De (m)	Change in thick. Dt=(to*De)/(1+eo) (m)	Change in total thickness (m)	Advetion thickness (m)
571	177-B4	0.620	3.274193548	0.04	0.009358491	0.151481208	0.075740604	3.811086758	E11	2.021	0.766037736	-1.253015956	-0.011726338		
		0.650	3.076923077	0.04	0.009811321	0.158810943	0.230886679	3.966232833	E11	2.014	0.754716981	-1.063199243	-0.010431389		
		0.980	1.704081633	0.04	0.014792453	0.239438038	0.43001117	4.165357324	FOUND	1.427	0.630188679	-0.277266347	-0.004101449		
		1.200	1.208333333	0.04	0.018113208	0.293189434	0.696324906	4.43167106	FOUND	1.208	0.547169811	0	0		
		1.250	1.12	0.04	0.018867925	0.30540566	0.995622453	4.730968607	FOUND	1.120	0.528301887	0	0	**-0.026259176**	**0.05390041**
572	155-B2	0.520	4.096153846	0.04	0.007849057	0.127048755	0.063524377	3.798870531	E12	3.233	0.803773585	-0.863165881	-0.006775038		
		0.473	4.602536998	0.04	0.007139623	0.115565502	0.184831506	3.92017766	E12	3.222	0.821509434	-1.380528643	-0.009856454		
		0.525	4.047619048	0.04	0.007924528	0.128270377	0.306749445	4.042095599	E10	2.792	0.801886792	-1.255756068	-0.009951274		
		0.620	3.274193548	0.04	0.009358491	0.151481208	0.446625238	4.181971392	E1	2.368	0.766037736	-0.906613654	-0.008484535		
		0.870	2.045977011	0.04	0.013132075	0.21256234	0.628647011	4.363993165	E8	1.724	0.671698113	-0.321763034	-0.004225416		
		1.010	1.623762376	0.04	0.015245283	0.246767774	0.858312068	4.593658222	FOUND	1.416	0.618867925	-0.20806565	-0.00317202	**-0.042464737**	**0.08716446**
574	153-B1	0.800	2.3125	0.04	0.012075472	0.195459623	0.097729811	3.833075965	E8	1.742	0.698113208	-0.570670061	-0.00689111		
		0.635	3.173228346	0.08	0.019169811	0.310292151	0.350605698	4.085951852	E1	2.373	0.760377358	-0.800185215	-0.0153394		
		0.650	3.076923077	0.04	0.009811321	0.158810943	0.585157245	4.320503399	E1	2.360	0.754716981	-0.717008153	-0.007034797		
		0.865	2.063583815	0.08	0.026113208	0.422681434	0.875903434	4.611249588	E8	1.717	0.673584906	-0.346853963	-0.00905747		
		1.280	1.0703125	0.12	0.057962264	0.938206189	1.556347245	5.291693399	FOUND	1.070	0.516981132	0	0	**-0.038322776**	**0.07866254**
577	120-B1	0.900	1.944444444	0.08	0.027169811	0.439784151	0.219892075	3.955238229	FOUND	1.433	0.660377358	-0.511749083	-0.013904126		
		0.900	1.944444444	0.08	0.027169811	0.439784151	0.659676226	4.39502238	FOUND	1.421	0.660377358	-0.523726134	-0.01422954		
		1.413	0.875442321	0.12	0.063984906	1.035691675	1.39741414	5.132760293	FOUND	0.875	0.466792453	0	0	**-0.028133666**	**0.05774805**
581	137-B1	0.657	3.03348554	0.06	0.014875472	0.240781823	0.120390911	3.855737065	E11	2.019	0.752075472	-1.014483757	-0.015090924		
		0.900	1.944444444	0.12	0.040754717	0.659676226	0.570619936	4.30596609	FOUND	1.423	0.660377358	-0.521400618	-0.021249535	**-0.036340459**	**0.07459357**
583	138-B2	0.475	4.578947368	0.08	0.014339623	0.232108302	0.116054151	3.851400305	E2	3.756	0.820754717	-0.823242523	-0.011804987	**-0.00015674**	**0.00032173**
584	139-B2	0.575	3.608695652	0.08	0.017358491	0.280973208	0.140486604	3.875832758	E1	2.385	0.783018868	-1.223235332	-0.021233519	**-0.000341279**	**0.00070052**

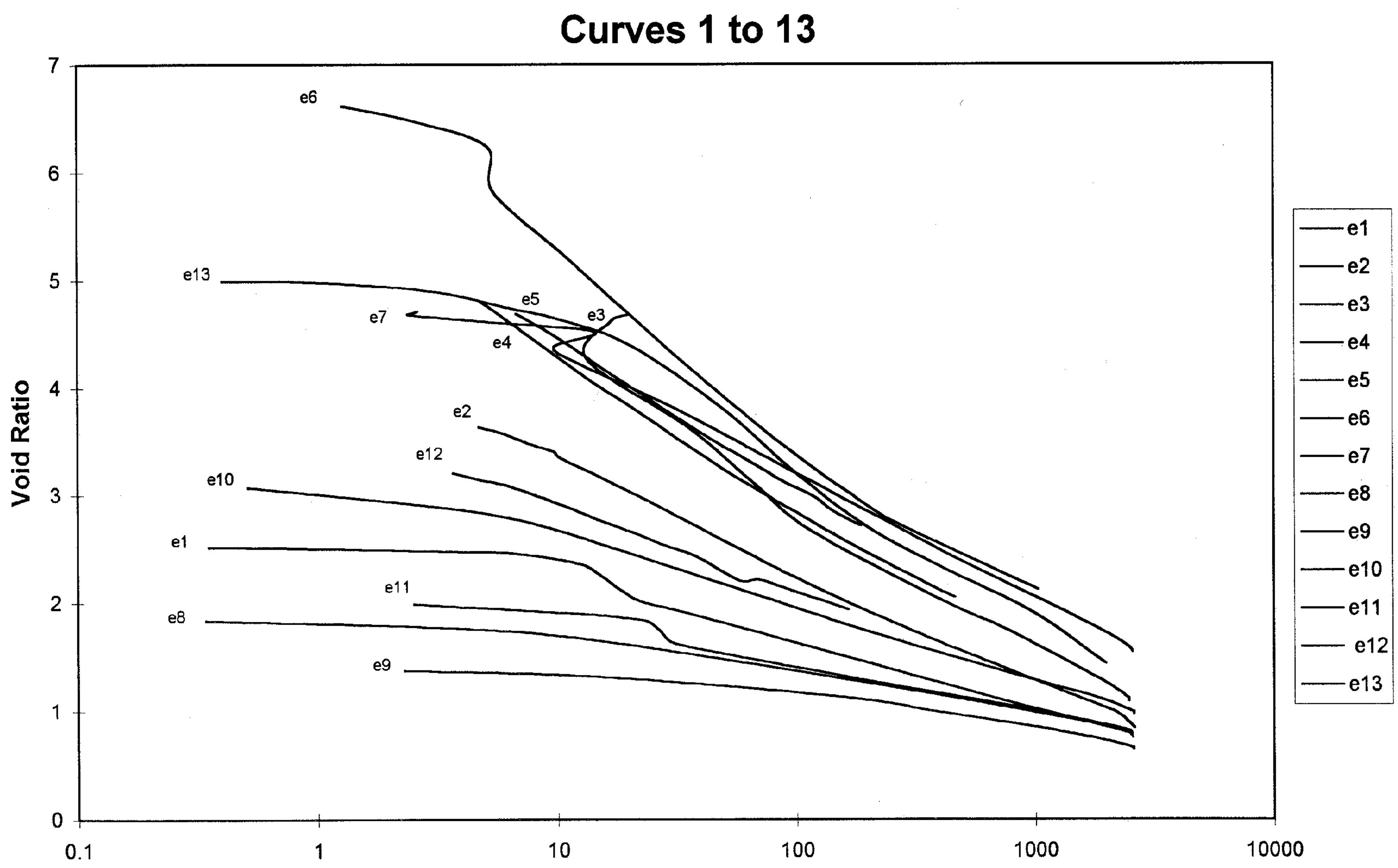


Figure C1. Void ratio effective stress for Palos Verdes sediments.

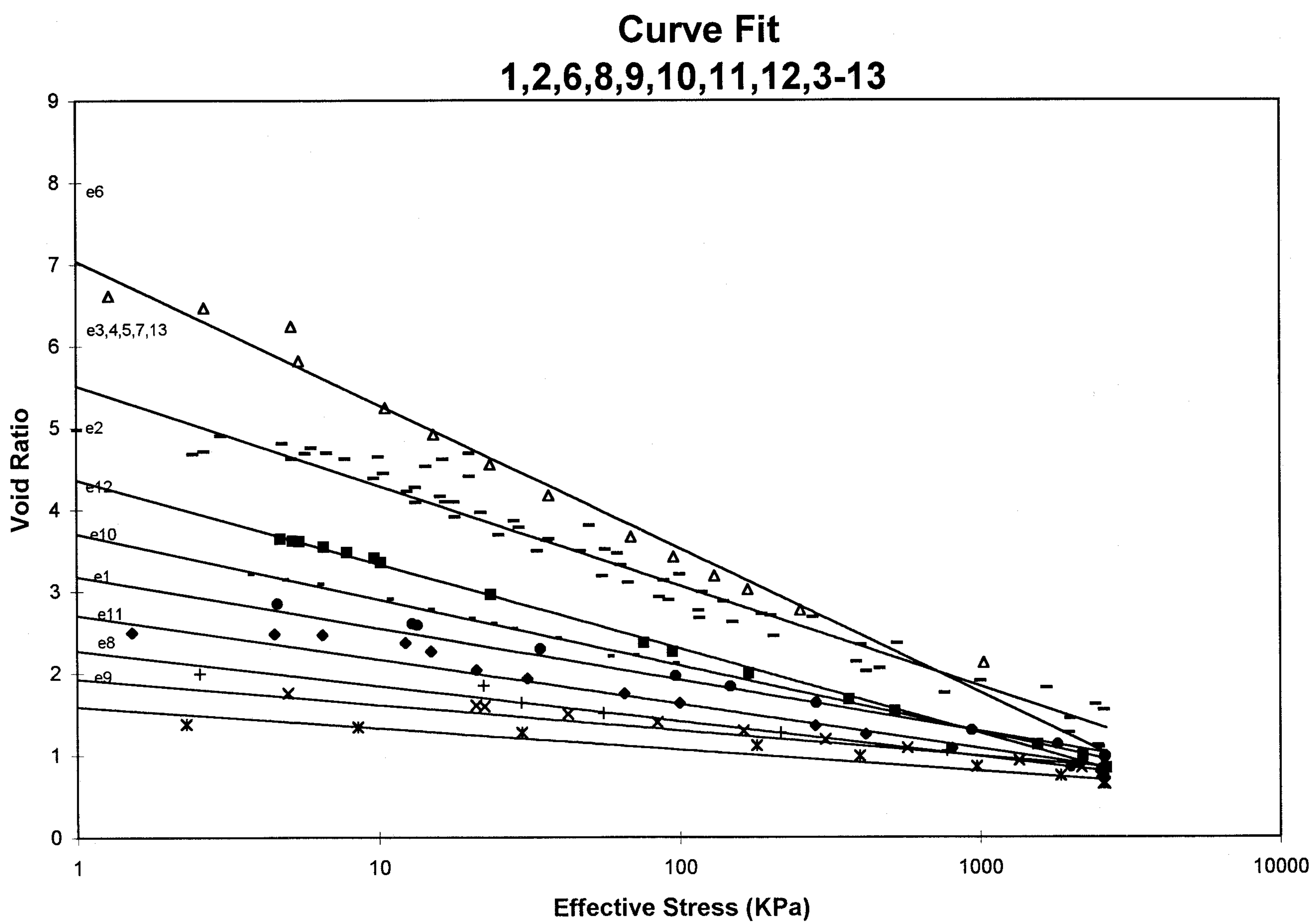


Figure C2. Curve fitted void ratio versus effective stress.

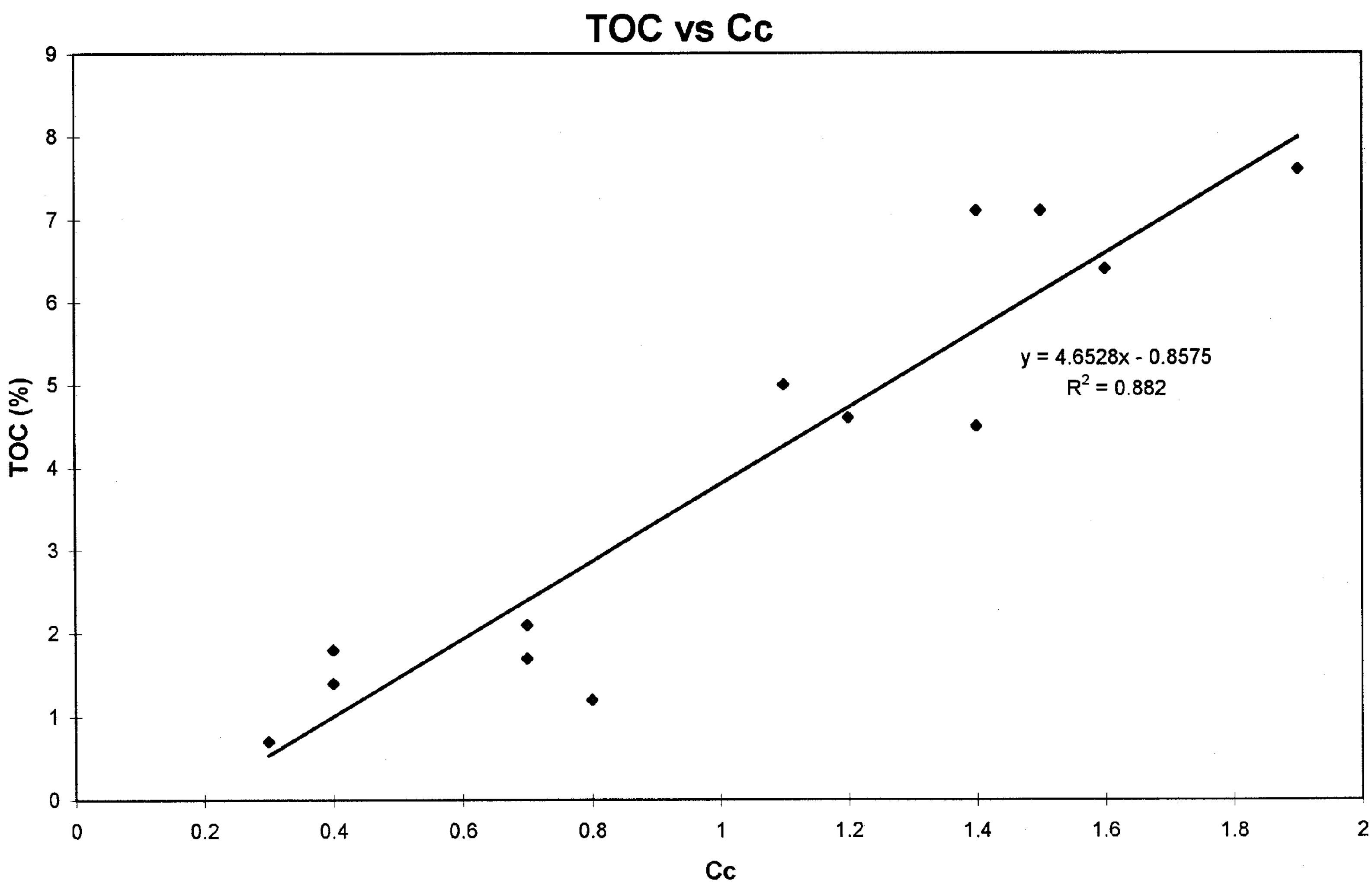


Figure C3. Total organic versus coefficient of consolidation.

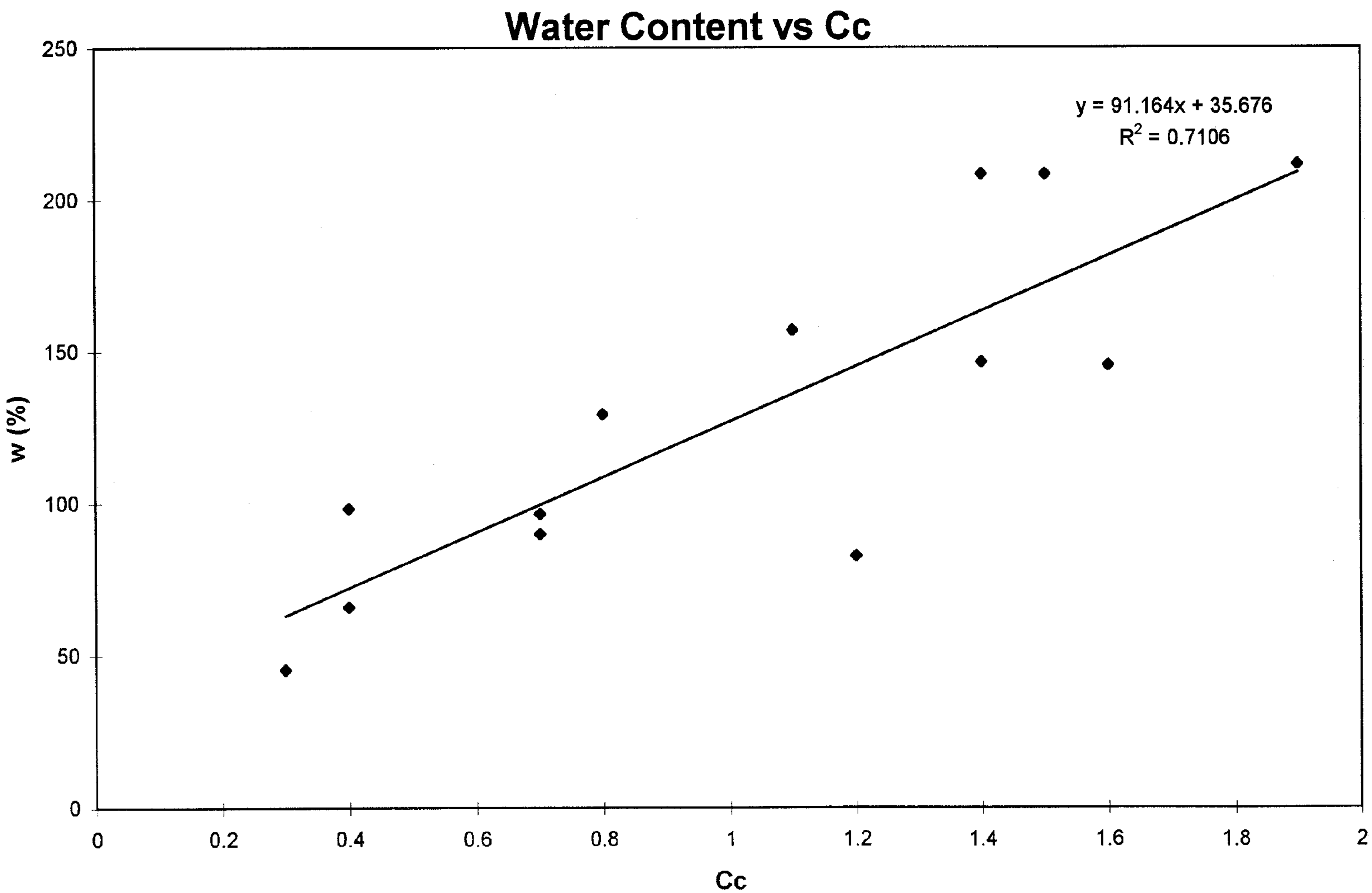


Figure C4. Water content versus coefficient of consolidation.

Appendix D - Cap Effectiveness Modeling

The U.S. Army Engineer Waterways Experiment Station (WES) is currently evaluating options for in situ capping for Palos Verdes (PV) shelf contaminated sediments. This appendix describes one aspect of the study, an evaluation of cap effectiveness modeling.

Purpose of Evaluations

The purpose of cap effectiveness modeling was to evaluate the potential flux or movement of contaminants upward into the cap and compare this behavior for a range of cap thicknesses. This information was then used in determining the appropriate cap thickness for chemical isolation of the contaminants and the relative contaminant exposures of a thick isolation cap as compared to a thin cap or no cap.

Approach

The effectiveness evaluation was based on a conservative analysis using straightforward and well-accepted principles. Laboratory tests results for consolidation (see Appendix C) and diffusion were used to define parameters necessary for the evaluations, and a combination of analytical calculations and numerical models were used to calculate the flux for the desired range of conditions.

Two types of flux evaluations were performed. First, a comparative analysis was carried out for a single contaminant profile (as defined by USGS station 556) considered representative of the more contaminated area or “hot spot” of the shelf. This comparative evaluation included a prediction of contaminant flux for a range of cap thicknesses and possible conditions related to the flux. The results of the comparative evaluation could be considered a “sensitivity analysis”. The results were then used in determining appropriate conditions for evaluation of flux for sediment contaminant profiles as defined by all other pertinent USGS stations. The results of these “production” model runs were then used to define the exposures to contaminants over the wider areas on the shelf considered for capping.

The total flux of contaminants from underlying contaminated sediment upward into a cap is the sum of the advective flux (due to consolidation) and the diffusive flux (due to molecular activity). Both the potential advective and diffusive fluxes were calculated as a part of this evaluation.

Advective Flux

Advection of Porewater

Advective flux is due to movement of porewater upward into the cap. No general gradient of groundwater flow was considered in these calculations due to the site conditions (see Chapter 2). Only consolidation of the contaminated material due to placement of the cap was considered. The magnitude of consolidation and the movement of porewater due to consolidation was calculated (see Appendix C). This evaluation indicated that the maximum consolidation was on the order of 10 percent of the applied cap thickness, and would therefore be only a few centimeters for the range of cap thicknesses under consideration. All porewater movement due to consolidation was confined in the lower portion of the cap layer.

Theoretical Basis for Advective Flux

Equilibrium partitioning was the theoretical basis for estimating contaminant concentrations in pore water advected by consolidation. Application of this theory to sediments is described by Hill, Myers, and Brannon (1988). The equilibrium assumption is valid when the advective velocity is slow relative to the rate at which contaminants desorb from sediments. This is a realistic assumption for fine grain sediment because advective velocities are usually very low due to the low hydraulic conductivity of the material.

A conservative assumption was made that no sorption of porewater contaminants to the cap material would occur until the consolidation process was complete. Once consolidation and water advection was complete, the porewater contaminants were assumed to adsorb to the cap material based on equilibrium partitioning.

Linear sorption can be assumed. Linear-equilibrium desorption for organic contaminants is described by the following equation:

$$C_s = K_d C_w \tag{1a}$$

where C_s is the equilibrium contaminant concentration in the sediment solids (mg/kg), C_w is the equilibrium contaminant concentration in the pore water (mg/ℓ), and K_d is the distribution coefficient (ℓ/kg). To calculate pore water organic contaminant concentration given a sediment contaminant concentration equation, 1a is rearranged to yield

$$C_w = Cs / K_d \tag{1b}$$

The distribution coefficient in equations 1a and 1b is a contaminant and sediment specific constant that describes the distribution of contaminant between sediment solids and pore water at equilibrium.

The distribution coefficients used in the evaluations were derived from laboratory diffusion tube tests conducted on representative samples of capping and PV shelf contaminated sediments (see discussion below).

The results of these calculations were used to adjust the concentration profiles to account for movement of contaminants due to advective flux prior to evaluation of long term diffusive flux using a numerical model. For all cases, the mass of contaminant moving into the cap via advection was very small.

Cap Effectiveness Testing

Laboratory tests were conducted to develop material specific values for the EA contaminated sediments and for representative dredged material caps. Results of these tests yield sediment specific and capping material specific values of partitioning coefficients used for the evaluation of advective flux due to consolidation and other parameters needed to model long term effectiveness. Samples of PV shelf material were obtained from USGS archived cores, and samples of the Queen's Gate sediment were obtained through CESPL.

Partition coefficients were measured using diffusion tubes (DiToro, Jeris, and Clarcia 1985). In this method, sediment is spiked with radiolabled contaminant, placed in small tubes, and covered with capping material. At times extending up to 1 year, selected tubes are sliced (100-250 um) using a microtome, and the thin slices are analyzed for radioactivity. The results are used to develop contaminant profiles from which coefficients that account for the sorptive properties of the cap materials can be calculated. The effective diffusion coefficient that accounts for sorptive DDT as measured by this test was 1.28×10^{-6} cm ^{2}/day for Queen's Gate capping material, yielding a partitioning coefficient, K_d, of 6.8×10^{-5} l/kg. This value was used in the estimation of advective flux. Details of the tests are presented in Addendum 1 to this appendix.

Diffusive Flux

Diffusive flux of contaminants was calculated using a refined version of the WES RECOVERY model, which was originally developed to estimate fluxes of contaminants from contaminated sediment layers to overlying water (Boyer et al. 1994). The model can estimate long term diffusive fluxes in a system composed of a completely mixed water column, a completely mixed sediment surface layer, and any number of clean and contaminated layers of material of varying properties and contaminant concentrations.

The analysis is based on the assumption that the overlying water column is well mixed. The contaminant is assumed to follow linear, reversible, equilibrium sorption and first-order decay kinetics. The physical representation of a system by RECOVERY consists of a well-mixed water column (i.e., zero-dimensional) underlain by a vertically-stratified sediment column (i.e., one-dimensional). The sediment is well-mixed horizontally but segmented vertically into a well-mixed surface (active) layer and underlying layers of sediment for which a varying profile may be defined. Since the mixed surface layer and underlying layers may be defined as clean or contaminated, the model is applicable to capping evaluations.

Processes incorporated in the RECOVERY model, in addition to sorption and decay, are volatilization, burial, resuspension, settling, advection, pore-water diffusion, and enhanced biodiffusion. For this analysis, pore-water diffusion and decay were assumed to be active for various runs. RECOVERY is based on the principles of equilibrium partitioning and considers diffusive flux from pore water to overlying water. The same equilibrium principles and partitioning coefficients as used for the advective flux analysis were applied in the RECOVERY diffusive flux.

The version of the RECOVERY model used for the evaluation of diffusive flux computes a partition coefficient for organic contaminants for each modeled layer via Karickoff et al. (1979).

$$K_d = 0.617 f_{oc} K_{ow} \tag{1}$$

where

f_{oc} = the weight fraction of organic carbon in the solid matter, g-orgC/g
K_{ow} = octanol-water partition coefficient, (mg/m^3-octanol)/(mg/m^3-water)

For this study the partition coefficient was computed using the relationships (Karickoff et al. 1989):

$$K_d = f_{oc} K_{oc} \tag{2}$$

and

$$\log_{10} K_{oc} = 0.00028 + 0.9831 \log_{10} K_{ow} \tag{3}$$

The value for $\log_{10} K_{ow}$ for DDT was 6.53 (Karickoff and Long 1995). The input values for K_{ow} in RECOVERY were specified to reflect these relationships and values. Different f_{oc} are allowed for the water column, mixed layer, and the

deep sediments. Analogous to other physico-chemical characteristics of the sediments, the f_{oc} can vary with depth (layers) in the sediments.

The mass transfer coefficient used in RECOVERY for diffusive exchange between mixed sediment layer porewater and the water column is related to fundamental parameters by

$$\nu_d = \frac{\phi D_s}{z'} \tag{3}$$

where

ν_d = diffusion mass-transfer coefficient at the sediment-water interface, m/yr

ϕ = porosity

D_s = diffusion coefficient in the sediment pore water, m^2/yr

z' = characteristic length over which the gradient exists at the sediment-water interface, m.

A value of 1 cm is assumed for z' based on Thomann and Mueller (1987). Also, D_s is related to molecular diffusivity D_m by the relation (Bernier 1980, Manheim and Waterman 1974)

$$D_s = D_m \phi^2$$

Diffusion Coefficients

Diffusion coefficients used in the model were literature values. The molecular diffusivity used was 4.85 x 10^{-6} cm^2/s (Thibodeaux 1996).

The effect of biodiffusion was simulated with the model by adjusting the molecular diffusion coefficient for the layer thickness affected by biodiffusion such that the rate of contaminant movement was analogous to the sediment biodiffusion rate measured by Drake, Sherwood, and Wiberg (1994). The model was run with a 15 cm completely mixed sediment layer, i.e., no concentration gradient; and a 15 cm enhanced diffusion layer, i.e., increase mixing of the dissolved pore water. Comparison simulations were made with a range of biodiffusion coefficients. The enhanced diffusion coefficient used for all the production runs was 2.5 x 10^{-5} cm^2/s, within the “one order” of magnitude increased mixing described by Drake, Sherwood, and Wiberg (1994). This approach is described by Berner (1980), with dissolved coefficient mixing of 1.5 x 10^{-5} cm^2/s (“tube” irrigation coefficient).

Results of Comparative Runs

A series of comparative runs were made for the profile at Station 556 to determine the effect of variations in depths of biodiffusion, biodiffusion coefficients, thickness of the isolation cap component, sediment deposition rate, and DDT degradation rate. Results of RECOVERY include the sediment profile, sediment contaminant concentrations, sediment porewater contaminant concentrations, and contaminant flux to the overlying water, all as a function of time. Profiles of the sediment contaminant concentrations can also be plotted. For most of the sensitivity runs, the total DDT sediment concentration in the mixed layer was used to illustrate the effect of the various parameters. Porewater concentrations and flux are a linear function of mixed layer sediment concentration.

All of the comparative runs were made for a simulated time period of 10,000 years in order to observe the long term behavior of the sediment profile and establish a peak value for the various parameters under the range of assumed conditions. Zero concentration of contaminants in the background water was assumed for all runs (this is a conservative assumption, yielding higher flux rates).

Cap Thickness Components

The design cap thickness for an isolation cap would be the sum of bioturbation, erosion, consolidation, operational, and isolation components. Other evaluations indicated that no cap thickness component is necessary for erosion (see Appendix A) or consolidation (see Appendix C). However, as noted above, consolidation of the EA sediment layer was considered in this evaluation of cap effectiveness. The operational component for potential variation in placed layer thickness and mixing of cap and EA sediments was considered as a part of the isolation component (see Chapter 3).

The cap design was therefore a function of the bioturbation component and isolation component. These components are closely linked, because the bioturbation process will directly affect the rate of movement of contaminants within that portion of the sediment and cap profile affected by bioturbation.

Biodiffusion Coefficient

Results of an evaluation of potential bioturbation (see Chapter 3) indicated that active bioturbation should be considered to a total depth of 30 cm with a mixed bioturbation depth of up to 15 cm. The bioturbation cap component would therefore be composed of two layers, one in which complete sediment mixing is assumed, and a second underlying layer in which an enhanced biodiffusion rate is assumed.

The effect of variation in the biodiffusion coefficient was evaluated by a series of simulations with the coefficient set at values of 2.5×10^{-4} cm^2/s, 2.5×10^{-5} cm^2/s, and 2.5×10^{-6} cm^2/s (an order of magnitude smaller and greater than the value described above). These runs were compared for the existing profile with no cap and for a 15 cm thin cap. Figures D1 and D2 show the DDT concentration in the mixed layer plotted as a function of time for the no cap and 15 cm cap, respectively. Each of these figures shows separate plots for the three values of biodiffusion coefficient and a fourth plot showing a comparison. Results indicate that the sediment concentration over the long term varies within one order of magnitude for a two order of magnitude variation in biodiffusion coefficient. All subsequent runs were made with a biodiffusion coefficient of 2.5×10^{-5} cm^2/s.

Isolation Thickness

With a mixed layer thickness of 15 cm and a biodiffusion layer thickness of an additional 15 cm, the total bioturbation cap thickness component is 30 cm, as discussed in Chapter 3. For the isolation cap, additional cap thickness would provide for chemical isolation and would serve to limit contaminant movement to molecular diffusion rates over the long term. A series of simulations were made with a mixed layer of 15 cm, a biodiffusion layer of 15 cm, and additional isolation cap component thicknesses of 0, 5, 10, and 15 cm, corresponding to total cap thicknesses of 30, 35, 40, and 45 cm. The results for DDT concentration in the mixed layer for the various thicknesses is shown in Figure D3. All the runs indicated effective isolation for a period of approximately 1000 years, after which the mixed layer concentration began to increase. These results clearly show the benefit of an isolation cap versus the thin cap as shown in Figure D2. A 5 cm isolation thickness (total cap thickness of 35 cm) results in an approximate two order of magnitude reduction in concentration over the 0 isolation thickness (total cap thickness of 30 cm). A 10 or 15 cm isolation thickness results in an approximate three order of magnitude reduction. Based on these results, a total cap thickness of 35 cm would provide effective long term isolation. However, considering that the cap layer thickness could vary by an estimated 10 cm because of an operational placement tolerance (see operational requirements in Chapter 3), an isolation cap thickness component of 15 cm, corresponding to a total isolation cap design thickness of 45 cm was determined appropriate for the production runs and for purposes of design and cost estimating. In this way, the target cap thickness for placement would be 45 cm, but areas later determined by monitoring to have thickness in excess 35 cm would not require additional cap material.

Biodiffusion Thickness

The effect of variation in the biodiffusion layer thickness was evaluated by a series of simulations with the biodiffusion layer thickness set at 0, 15, 35, and 85 cm. The mixed layer thickness of 15 cm and a biodiffusion layer thickness of an additional 15 cm, corresponding to the total bioturbation cap thickness component of 30 cm, as discussed in Chapter 3, was considered the baseline for

these runs and was used in the production runs. Figure D4 shows the DDT concentration in the mixed layer plotted as a function of time for the for the four values of biodiffusion layer thickness. Results show that the 15 cm biodiffusion layer thickness has a low peak concentration but it is many orders of magnitude higher than the case for no additional biodiffusion. Deeper depths of biodiffusion, even up to an 85 cm depth well into the EA layer, also show low peak concentrations, but they are three orders of magnitude higher than the 15 cm baseline condition. Based on these results, the 15 cm biodiffusion layer thickness is considered appropriately conservative and was used for the production runs.

Sediment Deposition

The assumption of new sediment deposition can have a major impact on long term simulations of cap effectiveness. Information developed as a part of the NOAA studies (see Chapter 3) indicates that no net deposition on the shelf should be assumed for future conditions. However, RECOVERY requires a nominal deposition rate be used in the model simulations. A deposition rate of 0.00004 m/year, essentially zero net deposition, was therefore set as a baseline condition. The effect of a net deposition rate on the model results was determined by a series of simulations with both the baseline condition and for a net deposition rate of 0.001 m/year (0.1 cm/year). These simulations were done for both a no cap condition and for the thin cap condition. Figure D5 shows the DDT concentration in the mixed layer plotted as a function of time for the for these runs. Results show that the assumption of sediment deposition has a dramatic effect. For the no cap condition, the deposition of new sediment results in a much quicker reduction in the mixed layer concentration, reaching zero concentration within a period of a few hundred years as compared to very slow reductions for the no deposition baseline. The effects are also dramatic for the thin cap, with the deposition result showing a much quicker increase to peak, a lower peak concentration and a decrease to zero concentration in several hundred years as compared to the no deposition baseline. However, the 1 cm/year deposition assumption corresponds to a deposition of 1 meter of new clean sediment being deposited each one hundred years, so the long term results are not surprising. The assumption of long term sediment deposition is not conservative and was not used in the production runs.

DDT Degradation

The potential degradation of contaminants is a process which would influence the long term presence of contaminants for the no cap and capping options. The effect of degradation of DDT in porewater for the entire sediment profile was considered for the no cap condition and both the 45 cm and 15 cm caps and was compared to the no degradation condition. Simulations were made for three degradation conditions in the sediment porewater corresponding to an infinite half life for DDT (no degradation) and half lives of 16 days and 100 days (Howard et al. 1991). The 100 days half-life was reported in Howard et al. (1991) for anaerobic decomposition of DDT, thus is used only in the sediment

profile and for the dissolved contaminant. It should be noted that the half life in porewater for this evaluation does not correspond to a half life for the entire mass of DDT in the sediment profile, only for the mass of DDT in the porewater.

Figures D6, D7, and D8 show the mixed layer DDT concentration plotted as a function of time for the no cap, 15 cm cap, and 45 cm cap, respectively. Each of these figures shows separate plots for the three degradation conditions and a fourth plot showing a comparison. Results indicate that degradation of DDT in porewater has virtually no effect on the long term sediment concentrations for the no cap condition and only a minor effect for the 15 cm cap. Peak concentrations are reduced with degradation by approximately a factor of three for the 45 cm cap. The assumption of no degradation was used for the production runs, since it would be more conservative.

Station 556 Long Term Results

A long term simulation was conducted for the Station 556 profile for the no cap, 15 cm thin cap, and 45 cm isolation cap conditions, using the selected or assumed parameters as discussed above. The thin cap consisted of a 15 cm mixed sediment layer. The isolation cap consisted of a 15 cm mixed sediment layer, underlain by a 15 cm biodiffusion layer, underlain by a 15 cm isolation layer, for a total cap thickness of 45 cm. The sediment DDT concentration in the mixed layer, the DDT pore water concentration in the mixed layer, and the DDT flux to the water column are plotted versus time in Figures D9, D10, and D11, respectively. Each of these figures show separate plots for the results for the no cap, 15 cm cap, and 45 cm cap conditions and a fourth plot showing a direct comparison.

For existing conditions (no cap), the flux and mixed layer sediment and pore water concentrations are at their peak initially, and decrease slowly with time. The initial mixed layer concentration is approximately 14 mg/kg and remains above a level of approximately 9 mg/kg for over a thousand years.

Placement of a 15 cm thin cap over the contaminated sediments results in an initially low DDT concentration in the mixed layer, but the concentration immediately begins to increase as DDT is moved upward by biodiffusion and the clean cap material and the underlying contaminated material are mixed due to bioturbation/ biodiffusion activity. The mixed layer concentration reaches approximately 12 mg/kg after about a thousand years, roughly equivalent to the initial concentration with no cap, then slowly begins to decrease.

Results for the 45 cm isolation cap showed essentially complete isolation for several hundred years followed by very low flux for extremely long time periods. The mixed layer sediment concentration reaches a peak only after several thousand years, and even then remains at a concentration over four orders of magnitude less than the no cap peak concentration. Based on the results of the

45 cm simulations, long term isolation was achieved. Therefore the 45 cm thickness is adequate for an isolation cap design.

Profiles showing the DDT sediment concentration for the full depth of the cap and EA sediment layer at various times following capping are shown in Figures D12, 13, and 14, for the no cap condition, 15 cm cap, and 45 cm cap. These plots show the slow decreases in the peak DDT concentration below the surficial mixed layer with time and the downward migration of the peak as DDT is diffused out of the upper portion of the profile into the water column.

Results for Production Runs

RECOVERY was used to calculate the sediment contaminant concentrations in the mixed layer, sediment porewater contaminant concentrations in the mixed layer, and contaminant flux to the overlying water for each sediment profile as defined by the USGS data. Production runs were made for all USGS box core station profiles, using the same parameters as given above for the long term simulations for Station 556. For purposes of comparison, the production run results are tabulated in Table D1 at an elapsed time of 5 years, 100 years, and at peak or maximum value. Production runs were made both PCB and DDT for the no cap, 15 cm thin cap, and 45 cm isolation cap.

References

Bernier, R.A. (1980). Early diagenesis. Princeton University Press, Princeton, NJ.

Boyer, J. M., Chapra, S. C., Ruiz, C. E., and Dortch, M. S. (1994). “RECOVERY, a mathematical model to predict the temporal response of surface water to contaminated sediments,” Technical Report W-94-4, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Brannon, J. M., Engler, R. M., Rose, J. R., Hunt, P. G., and Smith, Jr., I. (1976). "Selective analytical partitioning of sediments to evaluate potential mobility of chemical constituents during dredging and disposal operations," Technical Report D-76-7, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Di Toro, D.M., Jeris, J.S., and Ciarcia, D. (1985). "Diffusion and partitioning of hexachlorobipheny in sediments," *Environmental Science and Technology*, Vol 1, No. 2, pp 1169-1176.

Hill, D. O., Myers, T. E., and Brannon, J. M. (1988). "Development and application of techniques for predicting leachate quality in confined disposal facilities, Background and Theory," Miscellaneous Paper D-88-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Howard, P.H., Boethling, R.S., Jarvis, W.F., Meylan, W.M. and Michalenko, E.M. (1991). Handbook of Environmental Degradation Rates, Lewis Publishers, Chelsea, MI.

Karickhoff, S.W., Carriera, L.A., Melton, C., McDaniel, V.K., Vellino, A.N., and Nate, D.E. (1989). "Computer prediction of chemical reactivity. The ulitimate SAR," EPA 600/M-89-017, U.S. Environmental Protection Agency, Athens, GA.

Karickhoff, S.W. and Long, J.M. (1995). "Internal report on summary of measured, calculated and recommended LOG K_{OW} values," Environmental Research Laboratory Athens, GA, U.S. Environmental Protection Agency.

Manheim, F.T., and Waterman, L.S. (1974). "Diffusimetry (diffusion constant estimation) on sediment cores by resistivity probe," Initial Reports of the Deep Sea Drilling Project 22, 663-670.

Myers, T. E. and Brannon, J. M. (1988). "New Bedford Harbor Superfund Project, Acushnet River estuary engineering feasibility study of dredging and dredged material disposal alternatives; Report 5, evaluation of leachate quality," Technical Report EL-88-15, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Palermo, M. R., Shafer, R. A., Brannon, J. M., Myers, T. E., Truitt, C. L., Zappi, M. E., Skogerboe, J. G., Sturgis, T. C. Wade, R., Gunnison, D., Griffin, D. M., Tatum, H., Portzer, S., and Adamec, S. A. (1989). "Evaluation of dredged material disposal alternatives for US Navy Homeport at Everett, Washington," Technical Report EL-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Palermo, M.R., et al. (1993). "Long-term management strategy for dredged material disposal for naval weapons station, Yorktown, Yorktown, Virginia; Naval Supply Center, Cheatham Annex, Williamsburg, Virginia; and Naval Amphibious Base, Little Creek, Norfolk, Virginia; Phase II: formulation of alternatives," Miscellaneous Paper EL-93-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Steneker, R. C. H., Van Der Sloot, H. A., and Das, H. A. (1988). "Leaching studies on dredged material in oxidized and reduced state," The Science of the Total Environment, Vol. 68, pp 11-23.

Sturgis, T., and Gunnison, D. (1988). "A procedure for determining cap thickness for capping subaqueous dredged material deposits," Technical Note EEDP-0109, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Stark, T. D. (1996). "Program documentation and user's guide: PSDDF Primary Consolidation, Secondary Compression, and Desiccation of Dredged Fill," Instruction Report EL-96-XX, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Thibodeaux, L.J. (1996). Environmental Chemodynamics, John Wiley and Sons, New York, NY.

Thomann, R.V., and Mueller, J.A. (1987). "Principles of surface water quality modeling and control," Harper & Row, NY.

Table D1a
DDT Sediment Concentration, Pore Water Concentration and Flux for all USGS Stations, no cap

DDT Concentration No Cap (with adjusted values)

Station #	Flux from Sediment to Water Column (mg/sm-yr)				Sediment Concentration Mixed Bed (mg/kg)				Pore Water Concentration (mg/l)			
	initial	5 years	100 years	max	initial	5 years	100 years	max	initial	5 years	100 years	max
Above 70 m												
A												
550	1.35E-01	1.35E-01	1.29E-01	1.35E-01	9.84E+00	9.81E+00	9.39E+00	9.84E+00	2.16E-04	2.15E-04	2.06E-04	2.16E-04
555	2.83E-02	2.83E-02	2.76E-02	2.83E-02	2.50E+00	2.50E+00	2.44E+00	2.50E+00	8.40E-05	8.38E-05	8.19E-05	8.40E-05
556	1.54E-01	1.53E-01	1.48E-01	1.54E-01	1.36E+01	1.36E+01	1.31E+01	1.36E+01	2.55E-04	2.55E-04	2.45E-04	2.55E-04
564	1.51E-01	1.50E-01	1.43E-01	1.51E-01	1.68E+01	1.68E+01	1.59E+01	1.68E+01	2.53E-04	2.53E-04	2.40E-04	2.53E-04
574	2.93E-01	2.94E-01	2.96E-01	2.97E-01	3.99E+01	4.00E+01	4.03E+01	4.05E+01	4.67E-04	4.68E-04	4.71E-04	4.73E-04
577	4.58E-02	4.58E-02	4.45E-02	4.58E-02	5.80E+00	5.80E+00	5.63E+00	5.80E+00	1.03E-04	1.03E-04	1.00E-04	1.03E-04
B												
536	6.76E-02	6.73E-02	6.59E-02	6.76E-02	5.73E+00	5.71E+00	5.59E+00	5.73E+00	1.27E-04	1.27E-04	1.24E-04	1.27E-04
539	4.53E-02	4.52E-02	4.35E-02	4.53E-02	3.20E+00	3.19E+00	3.07E+00	3.20E+00	1.09E-04	1.09E-04	1.04E-04	1.09E-04
Outside A & B												
514	4.82E-02	4.82E-02	4.83E-02	4.85E-02	4.45E+00	4.44E+00	4.46E+00	4.47E+00	1.26E-04	1.26E-04	1.26E-04	1.27E-04
522	4.63E-02	4.62E-02	4.51E-02	4.63E-02	4.41E+00	4.40E+00	4.30E+00	4.41E+00	1.18E-04	1.18E-04	1.15E-04	1.18E-04
534	2.53E-02	2.52E-02	2.44E-02	2.53E-02	1.93E+00	1.92E+00	1.86E+00	1.93E+00	7.36E-05	7.33E-05	7.09E-05	7.36E-05
547	3.96E-03	3.95E-03	3.99E-03	4.00E-03	5.54E-01	5.53E-01	5.58E-01	5.60E-01	1.97E-05	1.97E-05	1.99E-05	1.99E-05
554	8.53E-03	8.49E-03	8.24E-03	8.53E-03	7.49E-01	7.45E-01	7.23E-01	7.49E-01	3.97E-05	3.95E-05	3.83E-05	3.97E-05
563	2.69E-03	2.69E-03	2.72E-03	2.72E-03	4.70E-01	4.70E-01	4.75E-01	4.75E-01	1.77E-05	1.77E-05	1.79E-05	1.79E-05
Below 70 m												
516	2.49E-03	2.49E-03	2.36E-03	2.49E-03	5.11E-01	5.10E-01	4.84E-01	5.11E-01	8.62E-06	8.59E-06	8.17E-06	8.62E-06
518	1.14E-01	1.13E-01	1.04E-01	1.14E-01	4.13E+00	4.11E+00	3.77E+00	4.13E+00	2.64E-04	2.63E-04	2.41E-04	2.64E-04
519	2.99E-02	2.97E-02	2.75E-02	2.99E-02	2.86E+00	2.84E+00	2.63E+00	2.86E+00	6.77E-05	6.73E-05	6.22E-05	6.77E-05
523	3.70E-02	3.69E-02	3.49E-02	3.70E-02	5.54E+00	5.52E+00	5.23E+00	5.54E+00	1.05E-04	1.05E-04	9.91E-05	1.05E-04
524	2.03E-02	2.02E-02	1.91E-02	2.03E-02	2.77E+00	2.76E+00	2.60E+00	2.77E+00	6.30E-05	6.28E-05	5.92E-05	6.30E-05
525	3.49E-02	3.36E-02	2.09E-02	3.49E-02	1.18E+00	1.13E+00	7.06E-01	1.18E+00	4.57E-05	4.39E-05	2.74E-05	4.57E-05
532	1.02E-01	1.01E-01	1.00E-01	1.02E-01	7.75E+00	7.73E+00	7.63E+00	7.75E+00	1.54E-04	1.53E-04	1.51E-04	1.54E-04
533	1.05E-01	1.05E-01	1.01E-01	1.05E-01	8.48E+00	8.46E+00	8.14E+00	8.48E+00	1.47E-04	1.46E-04	1.41E-04	1.47E-04
542	8.11E-03	8.06E-03	7.44E-03	8.11E-03	8.61E-01	8.56E-01	7.90E-01	8.61E-01	2.60E-05	2.58E-05	2.38E-05	2.60E-05
543	1.04E-02	1.04E-02	9.44E-03	1.04E-02	6.61E-01	6.56E-01	5.97E-01	6.61E-01	2.12E-05	2.10E-05	1.91E-05	2.12E-05
544	1.39E-01	1.38E-01	1.17E-01	1.39E-01	7.13E+00	7.07E+00	5.99E+00	7.13E+00	1.84E-04	1.82E-04	1.54E-04	1.84E-04
552	2.08E-01	2.08E-01	2.02E-01	2.08E-01	1.98E+01	1.98E+01	1.92E+01	1.98E+01	2.74E-04	2.73E-04	2.65E-04	2.74E-04
553	2.01E-02	2.00E-02	1.87E-02	2.01E-02	2.86E+00	2.85E+00	2.66E+00	2.86E+00	5.52E-05	5.49E-05	5.12E-05	5.52E-05
557	1.89E-01	1.90E-01	1.93E-01	1.93E-01	1.23E+01	1.23E+01	1.25E+01	1.25E+01	2.26E-04	2.26E-04	2.30E-04	2.30E-04
559	1.56E-01	1.56E-01	1.48E-01	1.56E-01	1.09E+01	1.09E+01	1.03E+01	1.09E+01	1.99E-04	1.98E-04	1.88E-04	1.99E-04
566	4.02E-02	4.01E-02	3.82E-02	4.02E-02	5.49E+00	5.47E+00	5.21E+00	5.49E+00	8.48E-05	8.45E-05	8.04E-05	8.48E-05
570	9.06E-02	9.07E-02	8.96E-02	9.08E-02	7.81E+00	7.82E+00	7.73E+00	7.83E+00	1.30E-04	1.30E-04	1.29E-04	1.31E-04
571	1.26E-01	1.26E-01	1.20E-01	1.26E-01	1.75E+01	1.74E+01	1.66E+01	1.75E+01	2.58E-04	2.58E-04	2.45E-04	2.58E-04
572	1.71E-01	1.71E-01	1.65E-01	1.71E-01	8.37E+00	8.34E+00	8.05E+00	8.37E+00	2.06E-04	2.05E-04	1.98E-04	2.06E-04
581	3.64E-02	3.62E-02	3.41E-02	3.64E-02	3.65E+00	3.64E+00	3.42E+00	3.65E+00	6.94E-05	6.91E-05	6.50E-05	6.94E-05
583	1.42E-01	1.41E-01	1.17E-01	1.42E-01	7.26E+00	7.19E+00	5.95E+00	7.26E+00	1.68E-04	1.66E-04	1.38E-04	1.68E-04
584	7.27E-02	7.21E-02	6.16E-02	7.27E-02	4.25E+00	4.21E+00	3.60E+00	4.25E+00	9.91E-05	9.83E-05	8.40E-05	9.91E-05
Average A	1.34E-01	1.34E-01	1.31E-01	1.35E-01	1.47E+01	1.47E+01	1.45E+01	1.48E+01	2.30E-04	2.30E-04	2.24E-04	2.31E-04
Average B	5.64E-02	5.62E-02	5.47E-02	5.64E-02	4.47E+00	4.45E+00	4.33E+00	4.47E+00	1.18E-04	1.18E-04	1.14E-04	1.18E-04
Average A & B	1.15E-01	1.15E-01	1.12E-01	1.15E-01	1.22E+01	1.22E+01	1.19E+01	1.22E+01	2.02E-04	2.02E-04	1.97E-04	2.03E-04
Average above 70 m	7.53E-02	7.52E-02	7.36E-02	7.56E-02	7.85E+00	7.85E+00	7.70E+00	7.89E+00	1.44E-04	1.43E-04	1.40E-04	1.44E-04
Average above 70 m (less A)	3.10E-02	3.09E-02	3.03E-02	3.10E-02	2.69E+00	2.68E+00	2.63E+00	2.69E+00	7.89E-05	7.87E-05	7.71E-05	7.90E-05
Average above 70 m (less A & B)	2.25E-02	2.24E-02	2.21E-02	2.25E-02	2.09E+00	2.09E+00	2.06E+00	2.10E+00	6.58E-05	6.57E-05	6.47E-05	6.60E-05
Average below 70 m	8.43E-02	8.40E-02	7.86E-02	8.45E-02	6.46E+00	6.44E+00	6.08E+00	6.47E+00	1.30E-04	1.29E-04	1.21E-04	1.30E-04

Table D1b
DDT Sediment Concentration, Pore Water Concentration and Flux for all USGS Stations, 15 cm cap

DDT Concentration 15 cm Cap (with adjusted values)

Station #	Flux from Sediment to Water Column (mg/sm-yr)				Sediment Concentration Mixed Bed (mg/kg)				Pore Water Concentration (mg/l)			
	initial	5 years	100 years	max	initial	5 years	100 years	max	initial	5 years	100 years	max
Above 70 m												
A												
550	2.4E-05	3.47E-04	3.70E-03	6.39E-03	2.10E-03	3.16E-02	3.36E-01	5.82E-01	1.21E-07	1.82E-06	1.93E-05	3.34E-05
555	2.3E-05	1.61E-04	1.63E-03	3.09E-03	2.06E-03	1.47E-02	1.48E-01	2.81E-01	1.18E-07	8.43E-07	8.51E-06	1.62E-05
556	4.1E-05	5.00E-04	5.73E-03	1.20E-02	3.64E-03	4.55E-02	5.21E-01	1.10E+00	2.09E-07	2.62E-06	3.00E-05	6.30E-05
564	3.6E-02	1.30E-03	1.42E-02	3.56E-02	4.98E-03	1.19E-01	1.30E+00	2.74E+00	2.86E-07	6.82E-06	7.45E-05	1.57E-04
574	1.5E-05	2.67E-04	3.10E-03	1.06E-02	1.33E-03	2.43E-02	2.82E-01	9.61E-01	7.64E-08	1.40E-06	1.62E-05	5.52E-05
577	9.4E-07	1.67E-05	2.03E-04	4.81E-04	4.01E-04	7.31E-03	8.85E-02	2.10E-01	4.80E-09	8.76E-08	1.06E-06	2.51E-06
B												
536	1.2E-05	2.56E-04	2.74E-03	4.83E-03	1.10E-03	2.33E-02	2.49E-01	4.39E-01	6.31E-08	1.34E-06	1.43E-05	2.53E-05
539	1.4E-05	1.84E-04	1.85E-03	3.33E-03	1.30E-03	1.68E-02	1.68E-01	3.03E-01	7.44E-08	9.63E-07	9.67E-06	1.74E-05
Outside A & B												
514	1.6E-05	2.09E-04	2.12E-03	3.84E-03	1.42E-03	1.90E-02	1.93E-01	3.49E-01	8.19E-08	1.09E-06	1.11E-05	2.01E-05
522	1.1E-05	2.04E-04	2.15E-03	3.85E-03	9.53E-04	1.86E-02	1.95E-01	3.51E-01	5.47E-08	1.07E-06	1.12E-05	2.02E-05
534	8.5E-06	1.23E-04	1.27E-03	2.30E-03	7.52E-04	1.12E-02	1.15E-01	2.09E-01	4.32E-08	6.45E-07	6.63E-06	1.20E-05
547	5.2E-06	3.20E-05	2.97E-04	5.49E-04	4.66E-04	2.91E-03	2.70E-02	5.00E-02	2.68E-08	1.67E-07	1.55E-06	2.87E-06
554	6.2E-06	1.19E-04	9.51E-04	2.12E-03	5.50E-04	1.09E-02	8.65E-02	1.93E-01	3.16E-08	6.24E-07	4.97E-06	1.11E-05
563	5.7E-06	3.02E-05	2.72E-04	4.94E-04	5.18E-04	2.75E-03	2.47E-02	4.50E-02	2.98E-08	1.58E-07	1.42E-06	2.58E-06
Below 70 m												
516	2.8E-06	3.97E-05	4.35E-04	7.30E-04	2.49E-04	3.61E-03	3.96E-02	6.65E-02	1.43E-08	2.08E-07	2.28E-06	3.82E-06
518	9.5E-06	2.28E-04	2.00E-03	4.06E-03	8.14E-04	2.08E-02	1.82E-01	3.69E-01	4.68E-08	1.19E-06	1.05E-05	2.12E-05
519	7.0E-06	1.36E-04	1.40E-03	2.58E-03	6.10E-04	1.23E-02	1.27E-01	2.35E-01	3.51E-08	7.10E-07	7.32E-06	1.35E-05
523	9.8E-06	1.80E-04	1.92E-03	3.43E-03	8.83E-04	1.64E-02	1.74E-01	3.12E-01	5.08E-08	9.41E-07	1.00E-05	1.79E-05
524	7.7E-06	1.38E-04	1.55E-03	2.72E-03	6.72E-04	1.26E-02	1.41E-01	2.47E-01	3.86E-08	7.22E-07	8.11E-06	1.42E-05
525	5.3E-06	8.21E-05	7.34E-04	1.05E-03	2.99E-04	7.47E-03	6.68E-02	9.52E-02	1.72E-08	4.29E-07	3.84E-06	5.47E-06
532	1.1E-05	2.76E-04	2.98E-03	5.19E-03	1.01E-03	2.51E-02	2.71E-01	4.72E-01	5.81E-08	1.44E-06	1.56E-05	2.71E-05
533	1.2E-05	2.66E-04	2.92E-03	5.01E-03	1.04E-03	2.42E-02	2.65E-01	4.56E-01	5.98E-08	1.39E-06	1.53E-05	2.62E-05
542	5.7E-06	7.24E-05	7.31E-04	1.32E-03	5.02E-04	6.59E-03	6.66E-02	1.20E-01	2.89E-08	3.79E-07	3.83E-06	6.89E-06
543	4.3E-06	4.87E-05	5.66E-04	3.12E-03	3.64E-04	4.43E-03	5.15E-02	2.84E-01	2.09E-08	2.55E-07	2.96E-06	1.63E-05
544	1.5E-05	3.68E-04	3.80E-03	6.68E-03	5.88E-04	3.35E-02	3.46E-01	6.08E-01	3.38E-08	1.92E-06	1.99E-05	3.49E-05
552	8.0E-06	2.27E-04	2.48E-03	4.32E-03	6.73E-04	2.06E-02	2.26E-01	3.93E-01	3.87E-08	1.19E-06	1.30E-05	2.26E-05
553	8.5E-06	1.36E-04	1.52E-03	2.63E-03	6.74E-04	1.23E-02	1.38E-01	2.39E-01	3.88E-08	7.09E-07	7.93E-06	1.38E-05
557	2.2E-05	4.06E-04	4.73E-03	1.04E-02	1.92E-03	3.69E-02	4.30E-01	9.43E-01	1.10E-07	2.12E-06	2.47E-05	5.42E-05
559	3.4E-06	8.62E-05	1.22E-03	9.35E-03	2.48E-04	7.84E-03	1.11E-01	8.51E-01	1.42E-08	4.51E-07	6.40E-06	4.89E-05
566	8.0E-06	2.10E-04	2.52E-03	6.90E-03	6.66E-04	1.92E-02	2.29E-01	6.27E-01	3.83E-08	1.10E-06	1.32E-05	3.61E-05
570	7.9E-06	1.76E-04	2.12E-03	4.51E-03	6.88E-04	1.60E-02	1.93E-01	4.10E-01	3.96E-08	9.22E-07	1.11E-05	2.36E-05
571	1.8E-05	4.13E-04	5.12E-03	1.24E-02	1.50E-03	3.76E-02	4.66E-01	1.13E+00	8.59E-08	2.16E-06	2.68E-05	6.49E-05
572	3.7E-05	5.84E-04	6.77E-03	1.35E-02	1.74E-03	5.31E-02	6.16E-01	1.23E+00	1.00E-07	3.05E-06	3.54E-05	7.06E-05
Average A	5.95E-03	4.33E-04	4.77E-03	1.14E-02	2.42E-03	4.03E-02	4.46E-01	9.77E-01	1.36E-07	2.26E-06	2.49E-05	5.46E-05
Average B	1.34E-05	2.20E-04	2.29E-03	4.08E-03	1.20E-03	2.00E-02	2.09E-01	3.71E-01	6.88E-08	1.15E-06	1.20E-05	2.13E-05
Average A & B	4.46E-03	3.79E-04	4.15E-03	9.54E-03	2.11E-03	3.53E-02	3.86E-01	8.26E-01	1.19E-07	1.98E-06	2.17E-05	4.63E-05
Average above 70 m	2.55E-03	2.68E-04	2.87E-03	6.39E-03	1.54E-03	2.48E-02	2.67E-01	5.57E-01	8.72E-08	1.40E-06	1.50E-05	3.14E-05
Average above 70 m (less A)	9.93E-06	1.45E-04	1.46E-03	2.66E-03	8.82E-04	1.32E-02	1.32E-01	2.42E-01	5.07E-08	7.57E-07	7.61E-06	1.39E-05
Average above 70 m (less A & B)	8.76E-06	1.20E-04	1.18E-03	2.19E-03	7.77E-04	1.09E-02	1.07E-01	1.99E-01	4.47E-08	6.26E-07	6.15E-06	1.15E-05
Average below 70 m	1.07E-05	2.14E-04	2.39E-03	5.26E-03	7.97E-04	1.95E-02	2.18E-01	4.78E-01	4.58E-08	1.12E-06	1.25E-05	2.75E-05

Table D1c
DDT Sediment Concentration, Pore Water Concentration and Flux for all USGS Stations, 45 cm cap

DDT Concentration 45 cm Cap (with adjusted values)

Station #	Flux from Sediment to Water Column (mg/sm-yr)				Sediment Concentration Mixed Bed (mg/kg)				Pore Water Concentration (mg/l)			
	initial	5 years	100 years	max	initial	5 years	100 years	max	initial	5 years	100 years	max
Above 70 m												
A												
550	1.10E-18	1.09E-18	4.06E-15	2.25E-09	1.00E-16	9.91E-17	3.69E-13	2.05E-07	5.75E-21	5.70E-21	2.12E-17	1.18E-11
555	1.10E-18	1.09E-18	9.80E-19	1.10E-18	1.00E-16	9.91E-17	8.92E-17	1.00E-16	5.75E-21	5.70E-21	5.13E-21	5.75E-21
556	1.10E-18	1.09E-18	9.27E-18	1.30E-10	1.00E-16	9.91E-17	8.44E-16	1.18E-08	5.75E-21	5.70E-21	4.85E-20	6.78E-13
564	1.10E-18	1.09E-18	1.23E-17	1.78E-10	1.00E-16	9.91E-17	1.12E-15	1.62E-08	5.75E-21	5.70E-21	6.45E-20	9.29E-13
574	1.10E-18	1.09E-18	9.80E-19	1.10E-18	1.00E-16	9.91E-17	8.92E-17	1.00E-16	5.75E-21	5.70E-21	5.13E-21	5.75E-21
577	1.10E-18	1.09E-18	9.80E-19	1.10E-18	1.00E-16	9.91E-17	8.92E-17	1.00E-16	5.75E-21	5.70E-21	5.13E-21	5.75E-21
B												
536	1.10E-18	1.09E-18	9.80E-19	1.44E-16	1.00E-16	9.91E-17	8.92E-17	1.31E-14	5.75E-21	5.70E-21	5.13E-21	7.52E-19
539	1.10E-18	1.09E-18	9.80E-19	1.70E-16	1.00E-16	9.91E-17	8.92E-17	1.54E-14	5.75E-21	5.70E-21	5.13E-21	8.87E-19
Outside A & B												
514	1.10E-18	1.09E-18	9.80E-19	1.10E-18	1.00E-16	9.91E-17	8.92E-17	1.00E-16	5.75E-21	5.70E-21	5.13E-21	5.75E-21
522	1.10E-18	1.09E-18	9.80E-19	1.24E-16	1.00E-16	9.91E-17	8.92E-17	1.13E-14	5.75E-21	5.70E-21	5.13E-21	6.50E-19
534	1.10E-18	1.09E-18	9.80E-19	1.10E-18	1.00E-16	9.91E-17	8.92E-17	1.00E-16	5.75E-21	5.70E-21	5.13E-21	5.75E-21
547	1.10E-18	1.09E-18	9.80E-19	1.10E-18	1.00E-16	9.91E-17	8.92E-17	1.00E-16	5.75E-21	5.70E-21	5.13E-21	5.75E-21
554	1.10E-18	1.09E-18	9.80E-19	1.10E-18	1.00E-16	9.91E-17	8.92E-17	1.00E-16	5.75E-21	5.70E-21	5.13E-21	5.75E-21
563	1.10E-18	1.09E-18	9.80E-19	1.10E-18	1.00E-16	9.91E-17	8.92E-17	1.00E-16	5.75E-21	5.70E-21	5.13E-21	5.75E-21
Below 70 m												
516	1.10E-18	1.09E-18	9.80E-19	1.10E-18	1.00E-16	9.91E-17	8.92E-17	1.00E-16	5.75E-21	5.70E-21	5.13E-21	5.75E-21
518	1.10E-18	1.09E-18	9.80E-19	1.10E-18	1.00E-16	9.91E-17	8.92E-17	1.00E-16	5.75E-21	5.70E-21	5.13E-21	5.75E-21
519	1.10E-18	1.09E-18	9.80E-19	1.10E-18	1.00E-16	9.91E-17	8.92E-17	1.00E-16	5.75E-21	5.70E-21	5.13E-21	5.75E-21
523	1.10E-18	1.09E-18	9.80E-19	1.10E-18	1.00E-16	9.91E-17	8.92E-17	1.00E-16	5.75E-21	5.70E-21	5.13E-21	5.75E-21
524	1.10E-18	1.09E-18	9.80E-19	1.10E-18	1.00E-16	9.91E-17	8.92E-17	1.00E-16	5.75E-21	5.70E-21	5.13E-21	5.75E-21
525	1.10E-18	1.09E-18	9.80E-19	1.10E-18	1.00E-16	9.91E-17	8.92E-17	1.00E-16	5.75E-21	5.70E-21	5.13E-21	5.75E-21
532	1.10E-18	1.09E-18	9.80E-19	1.10E-18	1.00E-16	9.91E-17	8.92E-17	1.00E-16	5.75E-21	5.70E-21	5.13E-21	5.75E-21
533	1.10E-18	1.09E-18	9.80E-19	1.10E-18	1.00E-16	9.91E-17	8.92E-17	1.00E-16	5.75E-21	5.70E-21	5.13E-21	5.75E-21
542	1.10E-18	1.09E-18	9.80E-19	1.10E-18	1.00E-16	9.91E-17	8.92E-17	1.00E-16	5.75E-21	5.70E-21	5.13E-21	5.75E-21
543	1.10E-18	1.09E-18	9.80E-19	1.10E-18	1.00E-16	9.91E-17	8.92E-17	1.00E-16	5.75E-21	5.70E-21	5.13E-21	5.75E-21
544	1.10E-18	1.09E-18	9.80E-19	1.10E-18	1.00E-16	9.91E-17	8.92E-17	1.00E-16	5.75E-21	5.70E-21	5.13E-21	5.75E-21
552	1.10E-18	1.09E-18	9.80E-19	1.10E-18	1.00E-16	9.91E-17	8.92E-17	1.00E-16	5.75E-21	5.70E-21	5.13E-21	5.75E-21
553	1.10E-18	1.09E-18	9.80E-19	1.10E-18	1.00E-16	9.91E-17	8.92E-17	1.00E-16	5.75E-21	5.70E-21	5.13E-21	5.75E-21
557	1.10E-18	1.09E-18	1.69E-13	7.83E-09	1.00E-16	9.91E-17	1.54E-11	7.12E-07	5.75E-21	5.70E-21	8.85E-16	4.10E-11
559	1.10E-18	1.09E-18	9.80E-19	1.91E-18	1.00E-16	9.91E-17	8.92E-17	1.74E-16	5.75E-21	5.70E-21	5.13E-21	9.98E-21
566	1.10E-18	1.09E-18	9.80E-19	1.10E-18	1.00E-16	9.91E-17	8.92E-17	1.00E-16	5.75E-21	5.70E-21	5.13E-21	5.75E-21
570	1.10E-18	1.09E-18	9.80E-19	9.01E-17	1.00E-16	9.91E-17	8.92E-17	8.20E-15	5.75E-21	5.70E-21	5.13E-21	4.72E-19
571	1.10E-18	1.09E-18	9.80E-19	1.10E-18	1.00E-16	9.91E-17	8.92E-17	1.00E-16	5.75E-21	5.70E-21	5.13E-21	5.75E-21
572	1.10E-18	1.09E-18	9.80E-19	8.76E-18	1.00E-16	9.91E-17	8.92E-17	7.98E-16	5.75E-21	5.70E-21	5.13E-21	4.58E-20
581	1.10E-18	1.09E-18	9.80E-19	1.10E-18	1.00E-16	9.91E-17	8.92E-17	1.00E-16	5.75E-21	5.70E-21	5.13E-21	5.75E-21
583	1.10E-18	1.09E-18	9.80E-19	1.10E-18	1.00E-16	9.91E-17	8.92E-17	1.00E-16	5.75E-21	5.70E-21	5.13E-21	5.75E-21
584	1.10E-18	1.09E-18	9.80E-19	1.10E-18	1.00E-16	9.91E-17	8.92E-17	1.00E-16	5.75E-21	5.70E-21	5.13E-21	5.75E-21
Average A	1.10E-18	1.09E-18	6.80E-16	4.27E-10	1.00E-16	9.91E-17	6.19E-14	3.89E-08	5.75E-21	5.70E-21	3.56E-18	2.23E-12
Average B	1.10E-18	1.09E-18	9.80E-19	1.57E-16	1.00E-16	9.91E-17	8.92E-17	1.43E-14	5.75E-21	5.70E-21	5.13E-21	8.19E-19
Average A & B	1.10E-18	1.09E-18	5.11E-16	3.20E-10	1.00E-16	9.91E-17	4.65E-14	2.91E-08	5.75E-21	5.70E-21	2.67E-18	1.68E-12
Average above 70 m	1.10E-18	1.09E-18	2.92E-16	1.83E-10	1.00E-16	9.91E-17	2.66E-14	1.67E-08	5.75E-21	5.70E-21	1.53E-18	9.57E-13
Average above 70 m (less A)	1.10E-18	1.09E-18	9.80E-19	5.54E-17	1.00E-16	9.91E-17	8.92E-17	5.04E-15	5.75E-21	5.70E-21	5.13E-21	2.90E-19
Average above 70 m (less A & B)	1.10E-18	1.09E-18	9.80E-19	2.16E-17	1.00E-16	9.91E-17	8.92E-17	1.97E-15	5.75E-21	5.70E-21	5.13E-21	1.13E-19
Average below 70 m	1.10E-18	1.09E-18	7.69E-15	3.56E-10	1.00E-16	9.91E-17	7.00E-13	3.24E-08	5.75E-21	5.70E-21	4.02E-17	1.86E-12

Table D1d
PCB Sediment Concentration, Pore Water Concentration and Flux for all USGS Stations, no cap

PCB Concentration No Cap (with adjusted values)

Station #	Flux from Sediment to Water Column (mg/sm-yr)				Sediment Concentration Mixed Bed (mg/kg)				Pore Water Concentration (mg/l)			
	initial	5 years	100 years	max	initial	5 years	100 years	max	initial	5 years	100 years	max
Above 70 m												
A												
550	1.15E-02	1.15E-02	1.10E-02	1.15E-02	8.56E-01	8.53E-01	8.18E-01	8.56E-01	1.83E-05	1.83E-05	1.75E-05	1.83E-05
555	3.13E-03	3.12E-03	3.04E-03	3.13E-03	2.83E-01	2.83E-01	2.75E-01	2.83E-01	9.28E-06	9.26E-06	9.02E-06	9.28E-06
556	1.65E-02	1.65E-02	1.57E-02	1.65E-02	1.50E+00	1.50E+00	1.42E+00	1.50E+00	2.74E-05	2.74E-05	2.61E-05	2.74E-05
564	1.31E-02	1.31E-02	1.25E-02	1.31E-02	1.50E+00	1.50E+00	1.43E+00	1.50E+00	2.21E-05	2.20E-05	2.11E-05	2.21E-05
574	2.76E-02	2.76E-02	2.71E-02	2.76E-02	3.85E+00	3.85E+00	3.79E+00	3.85E+00	4.40E-05	4.40E-05	4.33E-05	4.40E-05
577	5.98E-03	5.97E-03	5.80E-03	5.98E-03	7.76E-01	7.76E-01	7.53E-01	7.76E-01	1.35E-05	1.35E-05	1.31E-05	1.35E-05
B												
536	6.95E-03	6.92E-03	6.73E-03	6.95E-03	6.04E-01	6.02E-01	5.85E-01	6.04E-01	1.31E-05	1.30E-05	1.27E-05	1.31E-05
539	4.96E-03	4.95E-03	4.80E-03	4.96E-03	3.62E-01	3.61E-01	3.51E-01	3.62E-01	1.19E-05	1.19E-05	1.15E-05	1.19E-05
Outside A & B												
514	4.10E-03	4.10E-03	4.02E-03	4.10E-03	3.88E-01	3.87E-01	3.80E-01	3.88E-01	1.07E-05	1.07E-05	1.05E-05	1.07E-05
522	5.77E-03	5.77E-03	5.61E-03	5.77E-03	5.64E-01	5.63E-01	5.48E-01	5.64E-01	1.47E-05	1.47E-05	1.43E-05	1.47E-05
534	3.46E-03	3.45E-03	3.32E-03	3.46E-03	2.71E-01	2.70E-01	2.60E-01	2.71E-01	1.01E-05	1.00E-05	9.65E-06	1.01E-05
547	5.53E-04	5.52E-04	5.58E-04	5.60E-04	7.93E-02	7.92E-02	8.00E-02	8.04E-02	2.76E-06	2.75E-06	2.78E-06	2.79E-06
554	1.05E-03	1.05E-03	1.01E-03	1.05E-03	9.48E-02	9.44E-02	9.08E-02	9.48E-02	4.90E-06	4.88E-06	4.69E-06	4.90E-06
563	2.13E-04	2.13E-04	2.16E-04	2.16E-04	3.82E-02	3.82E-02	3.87E-02	3.87E-02	1.40E-06	1.41E-06	1.42E-06	1.42E-06
Below 70 m												
516	2.09E-04	2.08E-04	1.98E-04	2.09E-04	4.36E-02	4.35E-02	4.13E-02	4.36E-02	7.21E-07	7.19E-07	6.83E-07	7.21E-07
518	1.57E-02	1.56E-02	1.43E-02	1.57E-02	5.84E-01	5.81E-01	5.33E-01	5.84E-01	3.65E-05	3.63E-05	3.33E-05	3.65E-05
519	8.90E-03	8.85E-03	8.18E-03	8.90E-03	8.72E-01	8.67E-01	8.02E-01	8.72E-01	2.01E-05	2.00E-05	1.85E-05	2.01E-05
523	4.35E-03	4.34E-03	4.11E-03	4.35E-03	6.68E-01	6.66E-01	6.30E-01	6.68E-01	1.23E-05	1.23E-05	1.17E-05	1.23E-05
524	2.21E-03	2.20E-03	2.07E-03	2.21E-03	3.09E-01	3.08E-01	2.89E-01	3.09E-01	6.86E-06	6.83E-06	6.42E-06	6.86E-06
525	4.19E-03	4.03E-03	2.52E-03	4.19E-03	1.45E-01	1.39E-01	8.71E-02	1.45E-01	5.48E-06	5.27E-06	3.30E-06	5.48E-06
532	1.13E-02	1.13E-02	1.11E-02	1.13E-02	8.86E-01	8.84E-01	8.68E-01	8.86E-01	1.71E-05	1.71E-05	1.68E-05	1.71E-05
533	1.66E-02	1.66E-02	1.58E-02	1.66E-02	1.37E+00	1.37E+00	1.31E+00	1.37E+00	2.32E-05	2.31E-05	2.21E-05	2.32E-05
542	7.10E-04	7.05E-04	6.52E-04	7.10E-04	7.72E-02	7.67E-02	7.09E-02	7.72E-02	2.27E-06	2.26E-06	2.09E-06	2.27E-06
543	1.12E-03	1.11E-03	1.01E-03	1.12E-03	7.25E-02	7.20E-02	6.56E-02	7.25E-02	2.26E-06	2.25E-06	2.05E-06	2.26E-06
544	8.12E-03	8.05E-03	6.82E-03	8.12E-03	4.27E-01	4.23E-01	3.59E-01	4.27E-01	1.07E-05	1.06E-05	9.01E-06	1.07E-05
552	1.78E-02	1.78E-02	1.73E-02	1.78E-02	1.74E+00	1.74E+00	1.69E+00	1.74E+00	2.35E-05	2.34E-05	2.27E-05	2.35E-05
553	2.96E-03	2.95E-03	2.75E-03	2.96E-03	4.32E-01	4.30E-01	4.01E-01	4.32E-01	8.13E-06	8.09E-06	7.56E-06	8.13E-06
557	2.09E-02	2.09E-02	2.15E-02	2.18E-02	1.39E+00	1.39E+00	1.43E+00	1.45E+00	2.49E-05	2.49E-05	2.56E-05	2.59E-05
559	1.06E-02	1.06E-02	1.03E-02	1.06E-02	7.58E-01	7.58E-01	7.38E-01	7.58E-01	1.35E-05	1.35E-05	1.31E-05	1.35E-05
566	4.12E-03	4.11E-03	3.90E-03	4.12E-03	5.76E-01	5.74E-01	5.46E-01	5.76E-01	8.68E-06	8.65E-06	8.23E-06	8.68E-06
570	1.37E-02	1.37E-02	1.37E-02	1.38E-02	1.21E+00	1.21E+00	1.21E+00	1.22E+00	1.97E-05	1.97E-05	1.97E-05	1.99E-05
571	9.76E-03	9.73E-03	9.25E-03	9.76E-03	1.39E+00	1.39E+00	1.32E+00	1.39E+00	2.00E-05	2.00E-05	1.90E-05	2.00E-05
572	1.34E-02	1.34E-02	1.29E-02	1.34E-02	6.71E-01	6.70E-01	6.47E-01	6.71E-01	1.61E-05	1.61E-05	1.55E-05	1.61E-05
581	4.13E-03	4.12E-03	3.86E-03	4.13E-03	4.25E-01	4.23E-01	3.97E-01	4.25E-01	7.88E-06	7.85E-06	7.37E-06	7.88E-06
583	9.30E-03	9.21E-03	7.63E-03	9.30E-03	4.87E-01	4.82E-01	4.00E-01	4.87E-01	1.10E-05	1.09E-05	9.02E-06	1.10E-05
584	7.31E-03	7.25E-03	6.20E-03	7.31E-03	4.38E-01	4.34E-01	3.71E-01	4.38E-01	9.97E-06	9.88E-06	8.45E-06	9.97E-06
Average A	1.30E-02	1.30E-02	1.25E-02	1.30E-02	1.46E+00	1.46E+00	1.42E+00	1.46E+00	2.24E-05	2.24E-05	2.17E-05	2.24E-05
Average B	5.95E-03	5.93E-03	5.77E-03	5.95E-03	4.83E-01	4.81E-01	4.68E-01	4.83E-01	1.25E-05	1.25E-05	1.21E-05	1.25E-05
Average A & B	1.12E-02	1.12E-02	1.08E-02	1.12E-02	1.22E+00	1.21E+00	1.18E+00	1.22E+00	1.99E-05	1.99E-05	1.93E-05	1.99E-05
Average above 70 m	7.49E-03	7.48E-03	7.25E-03	7.49E-03	7.98E-01	7.96E-01	7.73E-01	7.98E-01	1.46E-05	1.46E-05	1.41E-05	1.46E-05
Average above 70 m (less A)	3.38E-03	3.37E-03	3.28E-03	3.38E-03	3.00E-01	2.99E-01	2.92E-01	3.00E-01	8.70E-06	8.68E-06	8.45E-06	8.71E-06
Average above 70 m (less A & B)	2.53E-03	2.52E-03	2.45E-03	2.53E-03	2.39E-01	2.39E-01	2.33E-01	2.39E-01	7.43E-06	7.42E-06	7.23E-06	7.44E-06
Average below 70 m	8.52E-03	8.49E-03	8.01E-03	8.56E-03	6.81E-01	6.78E-01	6.45E-01	6.84E-01	1.37E-05	1.36E-05	1.28E-05	1.37E-05

Table D1e
PCB Sediment Concentration, Pore Water Concentration and Flux for all USGS Stations, 15 cm cap

PCB Concentration 15 cm Cap (with adjusted values)

Station #	Flux from Sediment to Water Column (mg/sm-yr) initial	5 years	100 years	max	Sediment Concentration Mixed Bed (mg/kg) initial	5 years	100 years	max	Pore Water Concentration (mg/l) initial	5 years	100 years	max
Above 70 m												
A												
550	1.52E-07	3.28E-05	3.73E-04	6.50E-04	7.23E-06	3.06E-03	3.48E-02	6.06E-02	4.05E-10	1.72E-07	1.95E-06	3.40E-06
555	4.33E-09	1.73E-05	1.92E-04	3.33E-04	1.00E-16	1.25E-03	1.39E-02	2.41E-02	7.22E-21	9.02E-08	1.01E-06	1.74E-06
556	1.56E-07	4.25E-05	5.27E-04	1.12E-03	9.26E-06	3.96E-03	4.92E-02	1.04E-01	5.19E-10	2.22E-07	2.76E-06	5.85E-06
564	5.23E-07	1.02E-04	1.14E-03	2.32E-03	9.21E-06	7.37E-03	8.27E-02	1.68E-01	6.65E-10	5.32E-07	5.97E-06	1.21E-05
574	1.83E-07	5.74E-05	6.85E-04	1.88E-03	5.54E-06	4.16E-03	4.96E-02	1.36E-01	4.00E-10	3.00E-07	3.58E-06	9.82E-06
577	4.67E-05	9.04E-04	7.43E-04	9.11E-04	6.17E-07	4.25E-05	3.49E-05	4.28E-05	6.87E-08	4.73E-06	3.89E-06	4.77E-06
B												
536	9.37E-08	2.60E-05	2.91E-04	5.16E-04	3.16E-06	2.42E-03	2.72E-02	4.82E-02	1.77E-10	1.36E-07	1.52E-06	2.70E-06
539	6.47E-08	1.96E-05	2.12E-04	3.86E-04	3.70E-06	1.83E-03	1.98E-02	3.60E-02	2.07E-10	1.02E-07	1.11E-06	2.02E-06
Outside A & B												
514	8.07E-08	1.62E-05	1.78E-04	3.24E-04	1.77E-06	1.51E-03	1.66E-02	3.02E-02	9.90E-11	8.48E-08	9.31E-07	1.69E-06
522	5.00E-08	1.81E-05	2.09E-04	3.71E-04	3.21E-06	1.69E-03	1.95E-02	3.46E-02	1.80E-10	9.46E-08	1.09E-06	1.94E-06
534	2.80E-08	1.48E-05	1.63E-04	2.98E-04	3.13E-07	1.38E-03	1.52E-02	2.78E-02	1.75E-11	7.75E-08	8.55E-07	1.56E-06
547	2.02E-10	3.67E-06	4.02E-05	7.51E-05	1.00E-15	3.42E-04	3.75E-03	7.01E-03	5.61E-20	1.92E-08	2.10E-07	3.93E-07
554	3.53E-08	1.82E-05	1.49E-04	3.14E-04	6.84E-07	1.32E-03	1.08E-02	2.28E-02	4.94E-11	9.54E-08	7.80E-07	1.64E-06
563	1.65E-05	2.64E-04	1.98E-04	2.68E-04	4.48E-07	9.79E-06	7.33E-06	9.93E-06	6.32E-08	1.38E-06	1.03E-06	1.40E-06
Below 70 m												
516	6.37E-10	2.92E-06	3.44E-05	5.84E-05	1.00E-15	2.72E-04	3.21E-03	5.44E-03	5.61E-20	1.53E-08	1.80E-07	3.05E-07
518	1.89E-04	2.78E-05	2.54E-04	5.20E-04	8.76E-07	2.59E-03	2.37E-02	4.85E-02	4.91E-11	1.45E-07	1.33E-06	2.72E-06
519	2.67E-07	1.13E-04	1.22E-03	1.94E-03	5.10E-06	1.05E-02	1.13E-01	1.81E-01	2.86E-10	5.90E-07	6.36E-06	1.01E-05
523	2.48E-08	1.69E-05	1.91E-04	3.47E-04	6.18E-07	1.58E-03	1.78E-02	3.23E-02	3.46E-11	8.86E-08	9.99E-07	1.81E-06
524	5.05E-09	1.35E-05	1.60E-04	2.82E-04	1.00E-16	1.26E-03	1.49E-02	2.63E-02	5.61E-21	7.05E-08	8.37E-07	1.48E-06
525	1.66E-04	9.74E-04	6.89E-04	9.89E-04	2.31E-09	4.57E-05	3.24E-05	4.65E-05	2.57E-10	5.09E-06	3.60E-06	5.17E-06
532	4.36E-08	2.89E-05	3.25E-04	5.70E-04	2.20E-06	2.70E-03	3.04E-02	5.32E-02	1.23E-10	1.51E-07	1.70E-06	2.98E-06
533	1.17E-07	3.86E-05	4.44E-04	7.67E-04	2.99E-06	3.60E-03	4.14E-02	7.15E-02	1.67E-10	2.02E-07	2.32E-06	4.01E-06
542	2.58E-09	5.41E-06	6.14E-05	1.21E-04	1.00E-16	5.05E-04	5.73E-03	1.12E-02	5.61E-21	2.83E-08	3.21E-07	6.31E-07
543	3.79E-08	4.66E-06	5.12E-05	1.87E-04	7.27E-07	4.35E-04	4.77E-03	1.74E-02	4.08E-11	2.44E-08	2.68E-07	9.76E-07
544	3.46E-04	1.87E-03	1.39E-03	1.90E-03	7.53E-09	8.77E-05	6.52E-05	8.90E-05	8.39E-10	9.77E-06	7.26E-06	9.91E-06
552	6.90E-08	1.98E-05	2.24E-04	3.92E-04	1.41E-06	1.85E-03	2.09E-02	3.65E-02	7.89E-11	1.03E-07	1.17E-06	2.05E-06
553	1.24E-07	1.79E-05	2.12E-04	3.71E-04	9.35E-07	1.67E-03	1.98E-02	3.46E-02	5.24E-11	9.38E-08	1.11E-06	1.94E-06
557	2.71E-07	4.11E-05	4.55E-04	7.92E-04	7.08E-06	3.83E-03	4.25E-02	7.39E-02	3.97E-10	2.15E-07	2.38E-06	4.14E-06
559	1.30E-07	1.67E-05	1.94E-04	5.15E-04	1.03E-06	1.21E-03	1.41E-02	3.73E-02	7.47E-11	8.75E-08	1.02E-06	2.69E-06
566	6.54E-08	2.00E-05	2.46E-04	7.49E-04	6.86E-07	1.45E-03	1.78E-02	5.42E-02	4.95E-11	1.05E-07	1.29E-06	3.92E-06
570	1.50E-07	2.61E-05	3.22E-04	6.55E-04	2.39E-06	1.89E-03	2.33E-02	4.74E-02	1.72E-10	1.37E-07	1.68E-06	3.43E-06
571	1.48E-07	3.87E-05	4.90E-04	1.15E-03	1.83E-06	2.80E-03	3.55E-02	8.32E-02	1.32E-10	2.02E-07	2.56E-06	6.01E-06
572	2.66E-03	3.40E-03	3.06E-03	3.43E-03	2.65E-06	9.19E-06	8.27E-06	9.25E-06	5.13E-06	1.78E-05	1.60E-05	1.79E-05
Average A	7.95E-06	1.93E-04	6.10E-04	1.20E-03	5.31E-06	3.31E-03	3.84E-02	8.21E-02	1.18E-08	1.01E-06	3.19E-06	6.28E-06
Average B	7.92E-08	2.28E-05	2.52E-04	4.51E-04	3.43E-06	2.12E-03	2.35E-02	4.21E-02	1.92E-10	1.19E-07	1.32E-06	2.36E-06
Average A & B	5.99E-06	1.50E-04	5.21E-04	1.01E-03	4.84E-06	3.01E-03	3.47E-02	7.21E-02	8.88E-09	7.85E-07	2.72E-06	5.30E-06
Average above 70 m	4.61E-06	1.10E-04	3.65E-04	6.97E-04	3.22E-06	2.17E-03	2.45E-02	5.00E-02	9.61E-09	5.74E-07	1.91E-06	3.65E-06
Average above 70 m (less A)	2.10E-06	4.76E-05	1.80E-04	3.19E-04	1.66E-06	1.31E-03	1.41E-02	2.58E-02	8.00E-09	2.49E-07	9.42E-07	1.67E-06
Average above 70 m (less A & B)	2.78E-06	5.59E-05	1.56E-04	2.75E-04	1.07E-06	1.04E-03	1.10E-02	2.04E-02	1.06E-08	2.92E-07	8.17E-07	1.44E-06
Average below 70 m	1.77E-04	3.51E-04	5.27E-04	8.27E-04	1.61E-06	2.02E-03	2.26E-02	4.28E-02	2.70E-07	1.84E-06	2.76E-06	4.33E-06

Table D1f
PCB Sediment Concentration, Pore Water Concentration and Flux for all USGS Stations, 45 cm cap

PCB Concentration 45 cm Cap (with adjusted values)

Station #	Flux from Sediment to Water Column (mg/sm-yr)				Sediment Concentration Mixed Bed (mg/kg)				Pore Water Concentration (mg/l)			
	initial	5 years	100 years	max	initial	5 years	100 years	max	initial	5 years	100 years	max
Above 70 m												
A												
550	1.07E-18	1.06E-18	1.11E-17	6.52E-12	1.00E-16	9.91E-17	1.03E-15	6.08E-10	5.61E-21	5.56E-21	5.80E-20	3.41E-14
555	1.07E-18	1.06E-18	9.58E-19	1.07E-18	1.00E-16	9.91E-17	8.93E-17	1.00E-16	5.61E-21	5.56E-21	5.01E-21	5.61E-21
556	1.07E-18	1.06E-18	9.82E-19	4.32E-13	1.00E-16	9.91E-17	9.16E-17	4.03E-11	5.61E-21	5.56E-21	5.13E-21	2.26E-15
564	1.07E-18	1.06E-18	9.80E-19	4.06E-13	1.00E-16	9.91E-17	9.14E-17	3.79E-11	5.61E-21	5.56E-21	5.13E-21	2.12E-15
574	1.07E-18	1.06E-18	9.58E-19	1.07E-18	1.00E-16	9.91E-17	8.93E-17	1.00E-16	5.61E-21	5.56E-21	5.01E-21	5.61E-21
577	1.07E-18	1.06E-18	9.58E-19	1.07E-18	1.00E-16	9.91E-17	8.93E-17	1.00E-16	5.61E-21	5.56E-21	5.01E-21	5.61E-21
B												
536	1.07E-18	1.06E-18	9.58E-19	1.18E-18	1.00E-16	9.91E-17	8.93E-17	1.10E-16	5.61E-21	5.56E-21	5.01E-21	6.20E-21
539	1.07E-18	1.06E-18	9.58E-19	1.28E-18	1.00E-16	9.91E-17	8.93E-17	1.20E-16	5.61E-21	5.56E-21	5.01E-21	6.71E-21
Outside A & B												
514	1.07E-18	1.06E-18	9.58E-19	1.07E-18	1.00E-16	9.91E-17	8.93E-17	1.00E-16	5.61E-21	5.56E-21	5.01E-21	5.61E-21
522	1.07E-18	1.06E-18	9.58E-19	1.18E-18	1.00E-16	9.91E-17	8.93E-17	1.10E-16	5.61E-21	5.56E-21	5.01E-21	6.19E-21
534	1.07E-18	1.06E-18	9.58E-19	1.07E-18	1.00E-16	9.91E-17	8.93E-17	1.00E-16	5.61E-21	5.56E-21	5.01E-21	5.61E-21
547	1.07E-18	1.06E-18	9.58E-19	1.07E-18	1.00E-16	9.91E-17	8.93E-17	1.00E-16	5.61E-21	5.56E-21	5.01E-21	5.61E-21
554	1.07E-18	1.06E-18	9.58E-19	1.07E-18	1.00E-16	9.91E-17	8.93E-17	1.00E-16	5.61E-21	5.56E-21	5.01E-21	5.61E-21
563	1.07E-18	1.06E-18	9.58E-19	1.07E-18	1.00E-16	9.91E-17	8.93E-17	1.00E-16	5.61E-21	5.56E-21	5.01E-21	5.61E-21
Below 70 m												
516	1.07E-18	1.06E-18	9.58E-19	1.07E-18	1.00E-16	9.91E-17	8.93E-17	1.00E-16	5.61E-21	5.56E-21	5.01E-21	5.61E-21
518	1.07E-18	1.06E-18	9.58E-19	1.07E-18	1.00E-16	9.91E-17	8.93E-17	1.00E-16	5.61E-21	5.56E-21	5.01E-21	5.61E-21
519	1.07E-18	1.06E-18	9.58E-19	1.07E-18	1.00E-16	9.91E-17	8.93E-17	1.00E-16	5.61E-21	5.56E-21	5.01E-21	5.61E-21
523	1.07E-18	1.06E-18	9.58E-19	1.07E-18	1.00E-16	9.91E-17	8.93E-17	1.00E-16	5.61E-21	5.56E-21	5.01E-21	5.61E-21
524	1.07E-18	1.06E-18	9.58E-19	1.07E-18	1.00E-16	9.91E-17	8.93E-17	1.00E-16	5.61E-21	5.56E-21	5.01E-21	5.61E-21
525	1.07E-18	1.06E-18	9.58E-19	1.07E-18	1.00E-16	9.91E-17	8.93E-17	1.00E-16	5.61E-21	5.56E-21	5.01E-21	5.61E-21
532	1.07E-18	1.06E-18	9.58E-19	1.07E-18	1.00E-16	9.91E-17	8.93E-17	1.00E-16	5.61E-21	5.56E-21	5.01E-21	5.61E-21
533	1.07E-18	1.06E-18	9.58E-19	1.07E-18	1.00E-16	9.91E-17	8.93E-17	1.00E-16	5.61E-21	5.56E-21	5.01E-21	5.61E-21
542	1.07E-18	1.06E-18	9.58E-19	1.07E-18	1.00E-16	9.91E-17	8.93E-17	1.00E-16	5.61E-21	5.56E-21	5.01E-21	5.61E-21
543	1.07E-18	1.06E-18	9.58E-19	1.07E-18	1.00E-16	9.91E-17	8.93E-17	1.00E-16	5.61E-21	5.56E-21	5.01E-21	5.61E-21
544	1.07E-18	1.06E-18	9.58E-19	1.07E-18	1.00E-16	9.91E-17	8.93E-17	1.00E-16	5.61E-21	5.56E-21	5.01E-21	5.61E-21
552	1.07E-18	1.06E-18	9.58E-19	1.07E-18	1.00E-16	9.91E-17	8.93E-17	1.00E-16	5.61E-21	5.56E-21	5.01E-21	5.61E-21
553	1.07E-18	1.06E-18	9.58E-19	1.07E-18	1.00E-16	9.91E-17	8.93E-17	1.00E-16	5.61E-21	5.56E-21	5.01E-21	5.61E-21
557	1.07E-18	1.06E-18	5.29E-16	2.75E-11	1.00E-16	9.91E-17	4.94E-14	2.57E-09	5.61E-21	5.56E-21	2.77E-18	1.44E-13
559	1.07E-18	1.06E-18	9.58E-19	1.07E-18	1.00E-16	9.91E-17	8.93E-17	1.00E-16	5.61E-21	5.56E-21	5.01E-21	5.61E-21
566	1.07E-18	1.06E-18	9.58E-19	1.07E-18	1.00E-16	9.91E-17	8.93E-17	1.00E-16	5.61E-21	5.56E-21	5.01E-21	5.61E-21
570	1.07E-18	1.06E-18	9.58E-19	1.07E-18	1.00E-16	9.91E-17	8.93E-17	1.00E-16	5.61E-21	5.56E-21	5.01E-21	5.62E-21
571	1.07E-18	1.06E-18	9.58E-19	1.07E-18	1.00E-16	9.91E-17	8.93E-17	1.00E-16	5.61E-21	5.56E-21	5.01E-21	5.61E-21
572	1.07E-18	1.06E-18	9.58E-19	1.07E-18	1.00E-16	9.91E-17	8.93E-17	1.00E-16	5.61E-21	5.56E-21	5.01E-21	5.61E-21
581	1.07E-18	1.06E-18	9.58E-19	1.07E-18	1.00E-16	9.91E-17	8.93E-17	1.00E-16	5.61E-21	5.56E-21	5.01E-21	5.61E-21
583	1.07E-18	1.06E-18	9.58E-19	1.07E-18	1.00E-16	9.91E-17	8.93E-17	1.00E-16	5.61E-21	5.56E-21	5.01E-21	5.61E-21
584	1.07E-18	1.06E-18	9.58E-19	1.07E-18	1.00E-16	9.91E-17	8.93E-17	1.00E-16	5.61E-21	5.56E-21	5.01E-21	5.61E-21
Average A	1.07E-18	1.06E-18	2.65E-18	1.23E-12	1.00E-16	9.91E-17	2.48E-16	1.14E-10	5.61E-21	5.56E-21	1.39E-20	6.41E-15
Average B	1.07E-18	1.06E-18	9.58E-19	1.23E-18	1.00E-16	9.91E-17	8.93E-17	1.15E-16	5.61E-21	5.56E-21	5.01E-21	6.45E-21
Average A & B	1.07E-18	1.06E-18	2.23E-18	9.19E-13	1.00E-16	9.91E-17	2.08E-16	8.58E-11	5.61E-21	5.56E-21	1.17E-20	4.81E-15
Average above 70 m	1.07E-18	1.06E-18	1.69E-18	5.25E-13	1.00E-16	9.91E-17	1.57E-16	4.90E-11	5.61E-21	5.56E-21	8.81E-21	2.75E-15
Average above 70 m (less A)	1.07E-18	1.06E-18	9.58E-19	1.13E-18	1.00E-16	9.91E-17	8.93E-17	1.05E-16	5.61E-21	5.56E-21	5.01E-21	5.89E-21
Average above 70 m (less A & B)	1.07E-18	1.06E-18	9.58E-19	1.09E-18	1.00E-16	9.91E-17	8.93E-17	1.02E-16	5.61E-21	5.56E-21	5.01E-21	5.70E-21
Average below 70 m	1.07E-18	1.06E-18	2.50E-17	1.25E-12	1.00E-16	9.91E-17	2.33E-15	1.17E-10	5.61E-21	5.56E-21	1.31E-19	6.55E-15

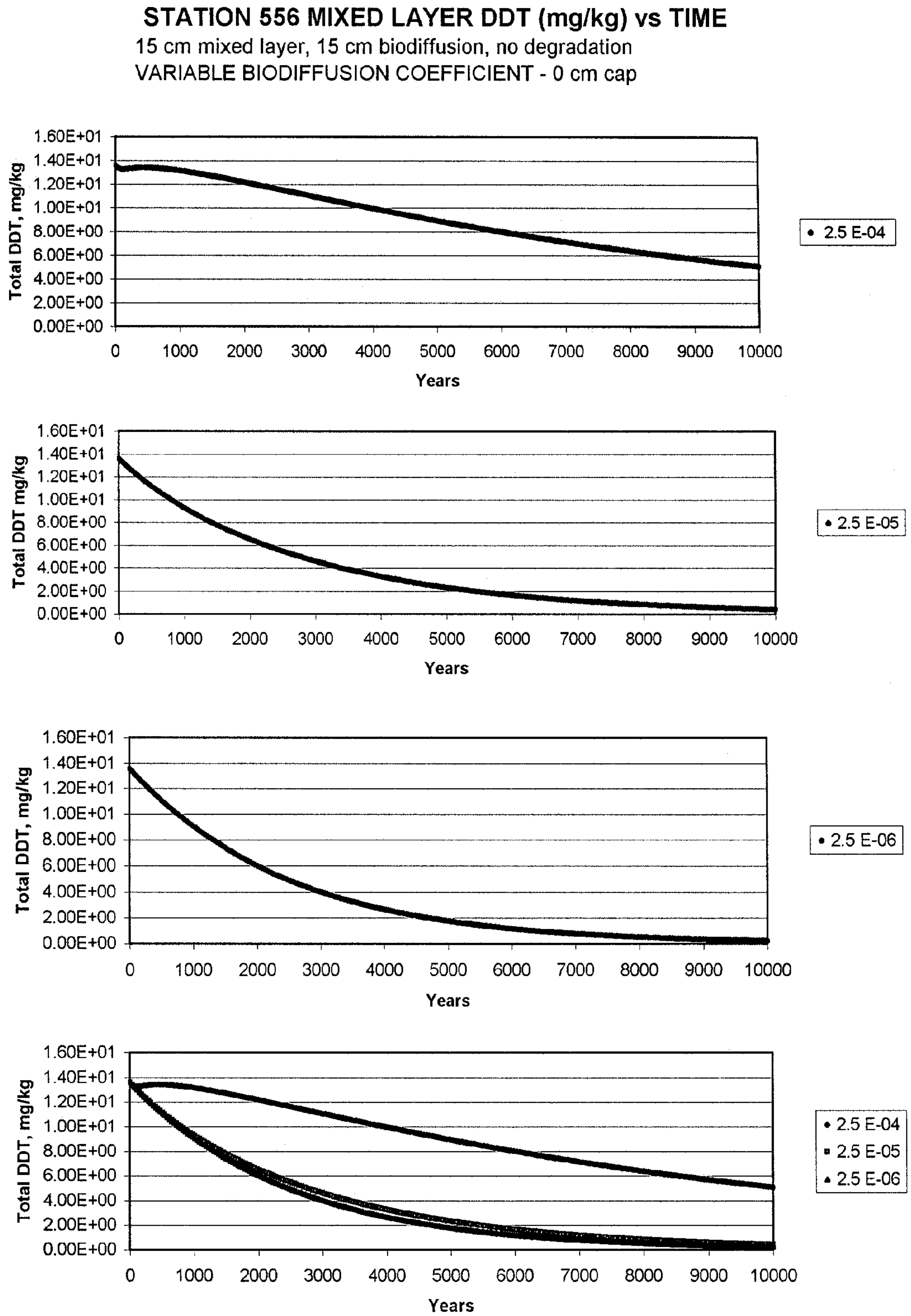


Figure D1. Comparative plots of DDT sediment concentration in the mixed layer, Station 556, showing effect of varying biodiffusion coefficient, no cap condition

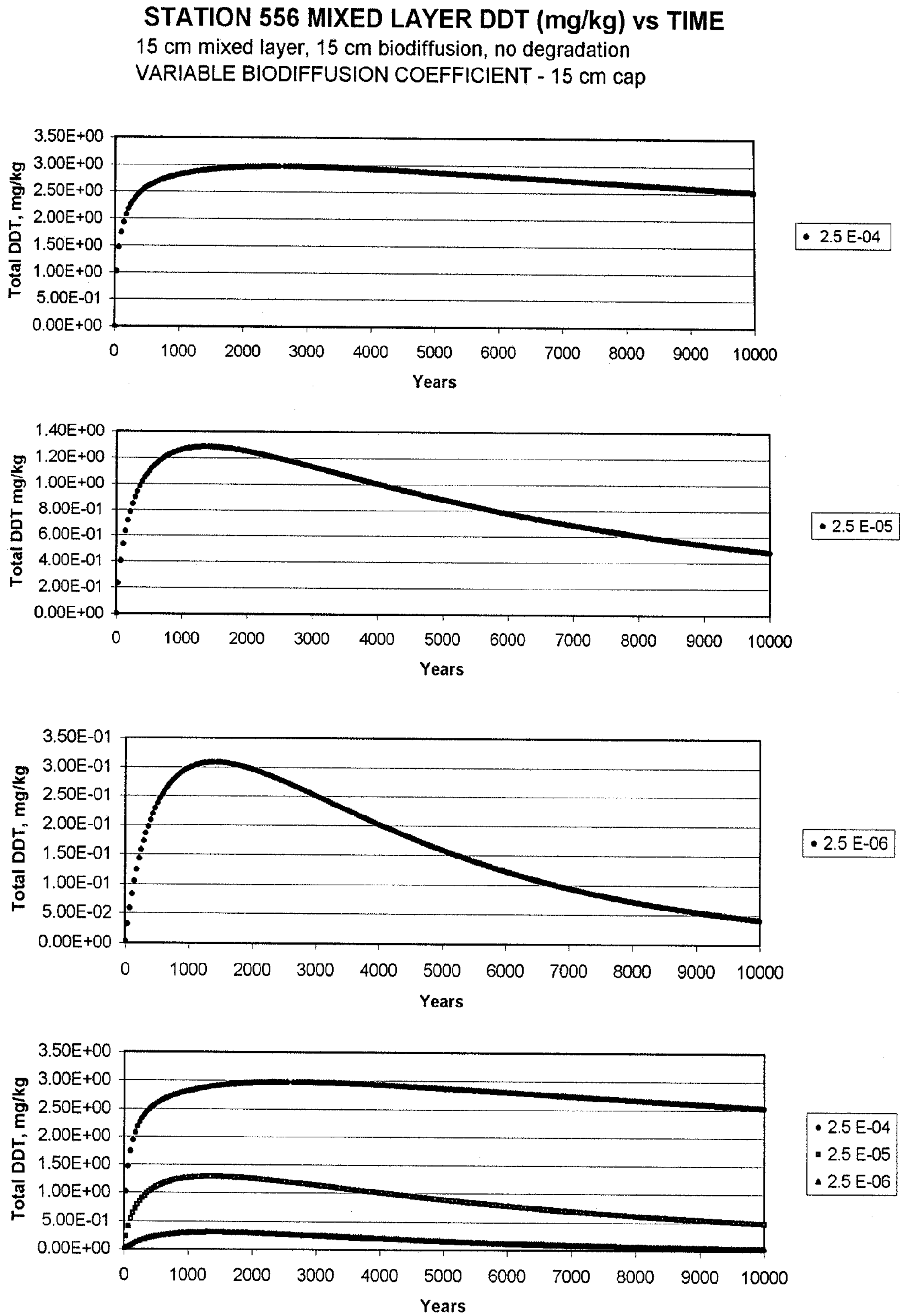


Figure D2. Comparative plots of DDT sediment concentration in the mixed layer, Station 556, showing effect of varying biodiffusion coefficient, 15 cm cap

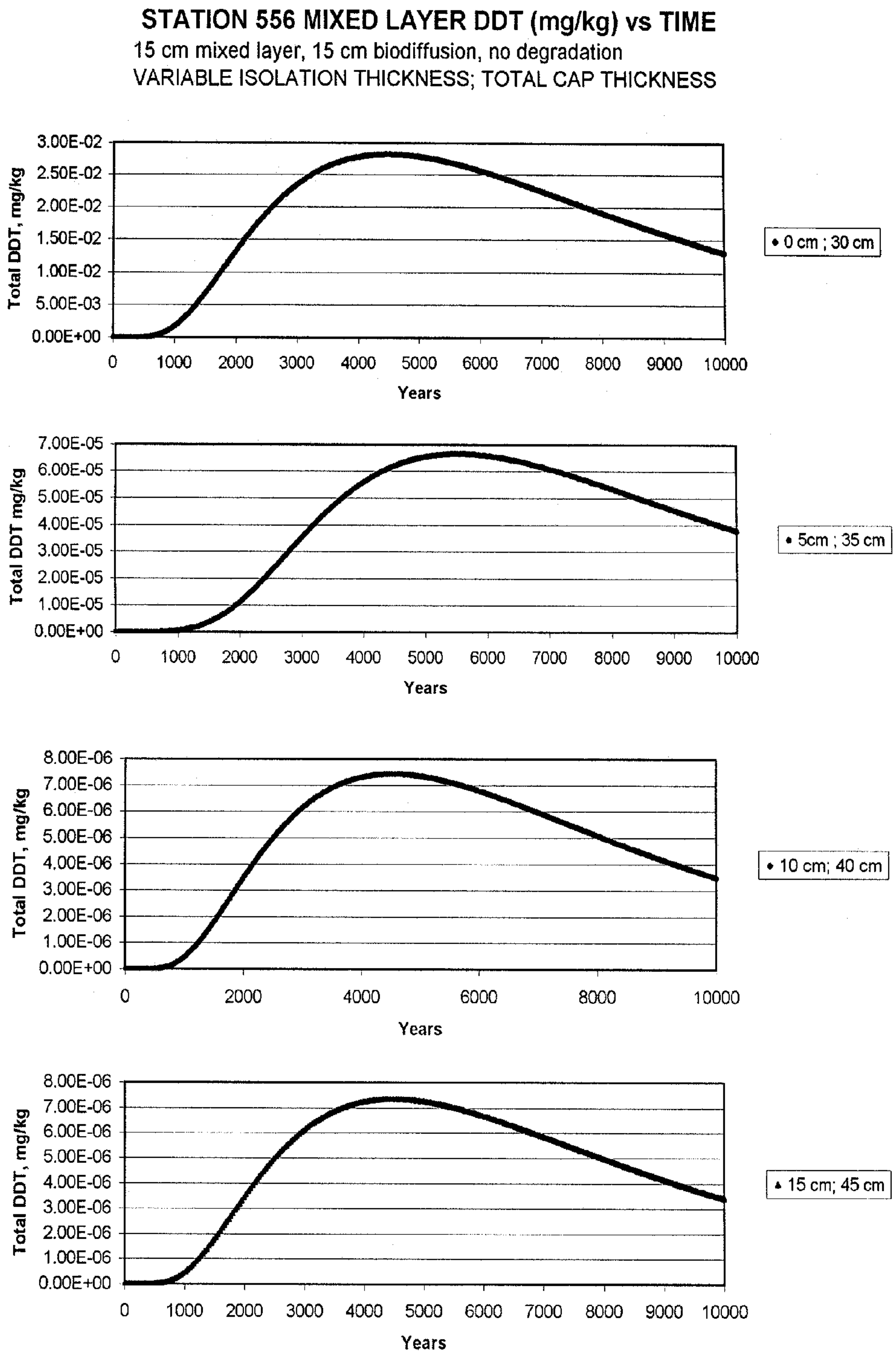


Figure D3. Comparative plots of DDT sediment concentration in the mixed layer, Station 556, showing effect of varying isolation thickness component

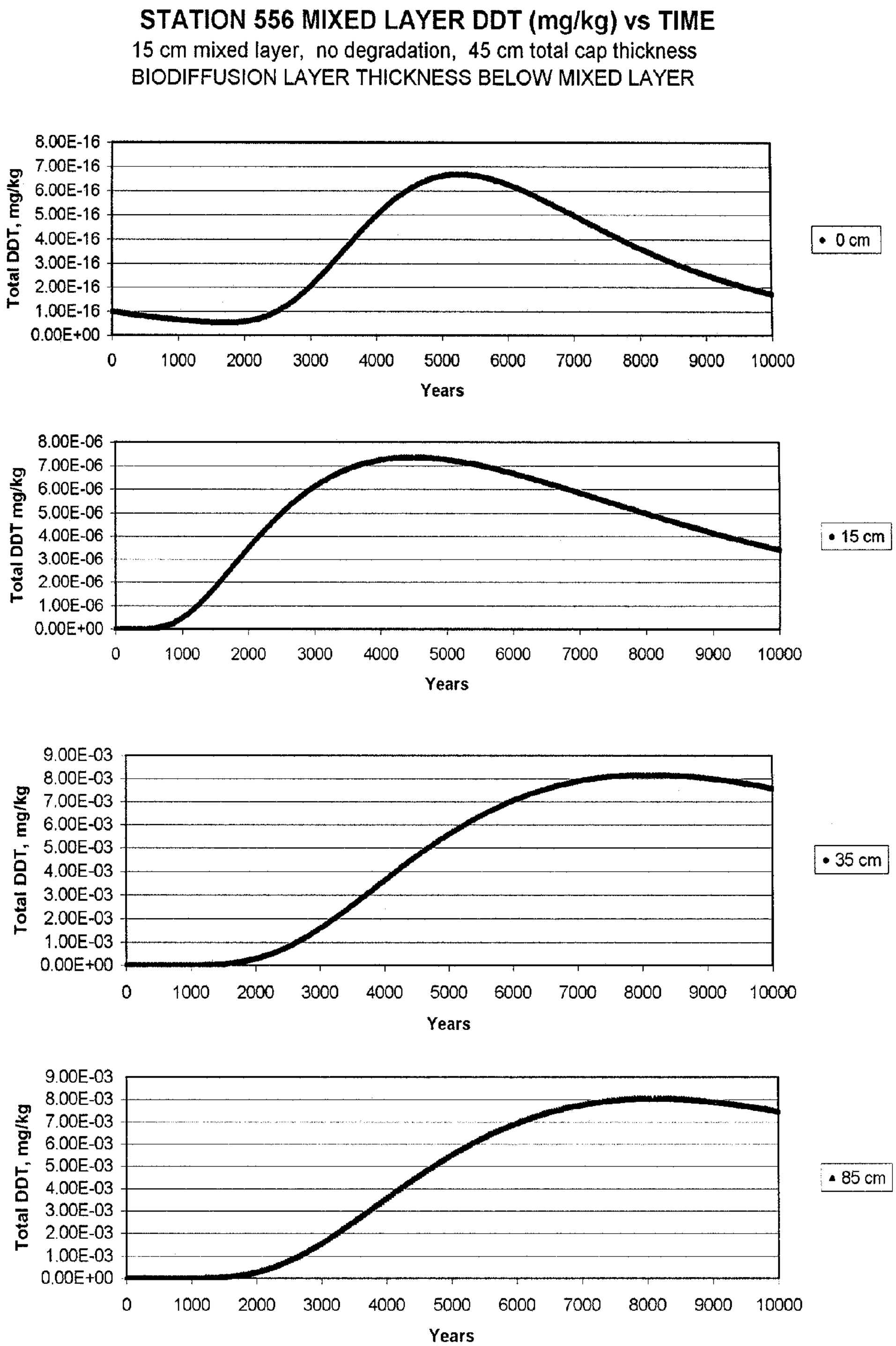


Figure D4. Comparative plots of DDT sediment concentration in the mixed layer, Station 556, showing effect of varying biodiffusion layer thickness, 45 cm cap

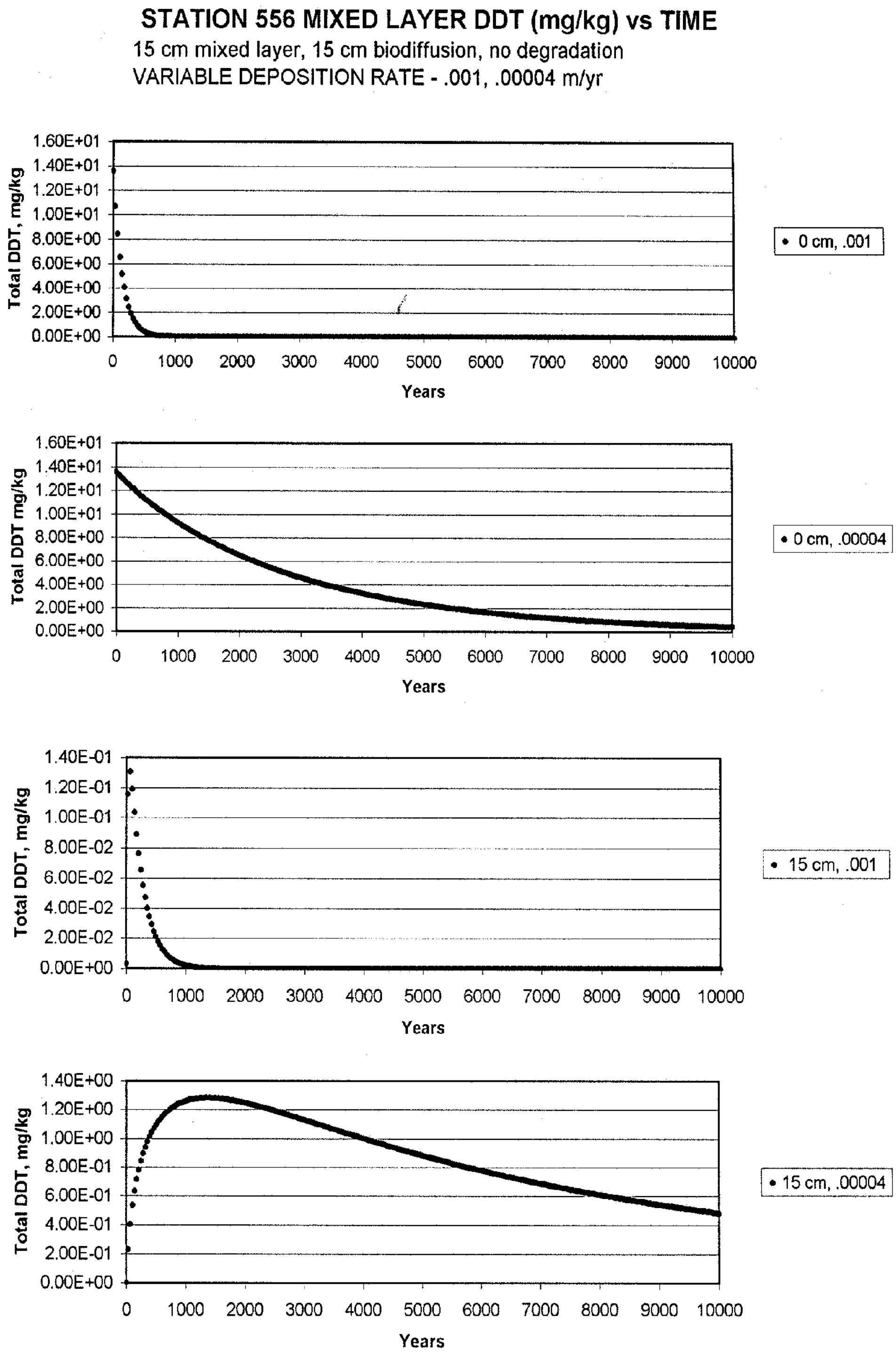


Figure D5. Comparative plots of DDT sediment concentration in the mixed layer, Station 556, showing effect of assumed sediment deposition

STATION 556 MIXED LAYER DDT (mg/kg) vs TIME

15 cm mixed layer, 15 cm biodiffusion

VARIABLE DEGRADATION - 0 cm cap

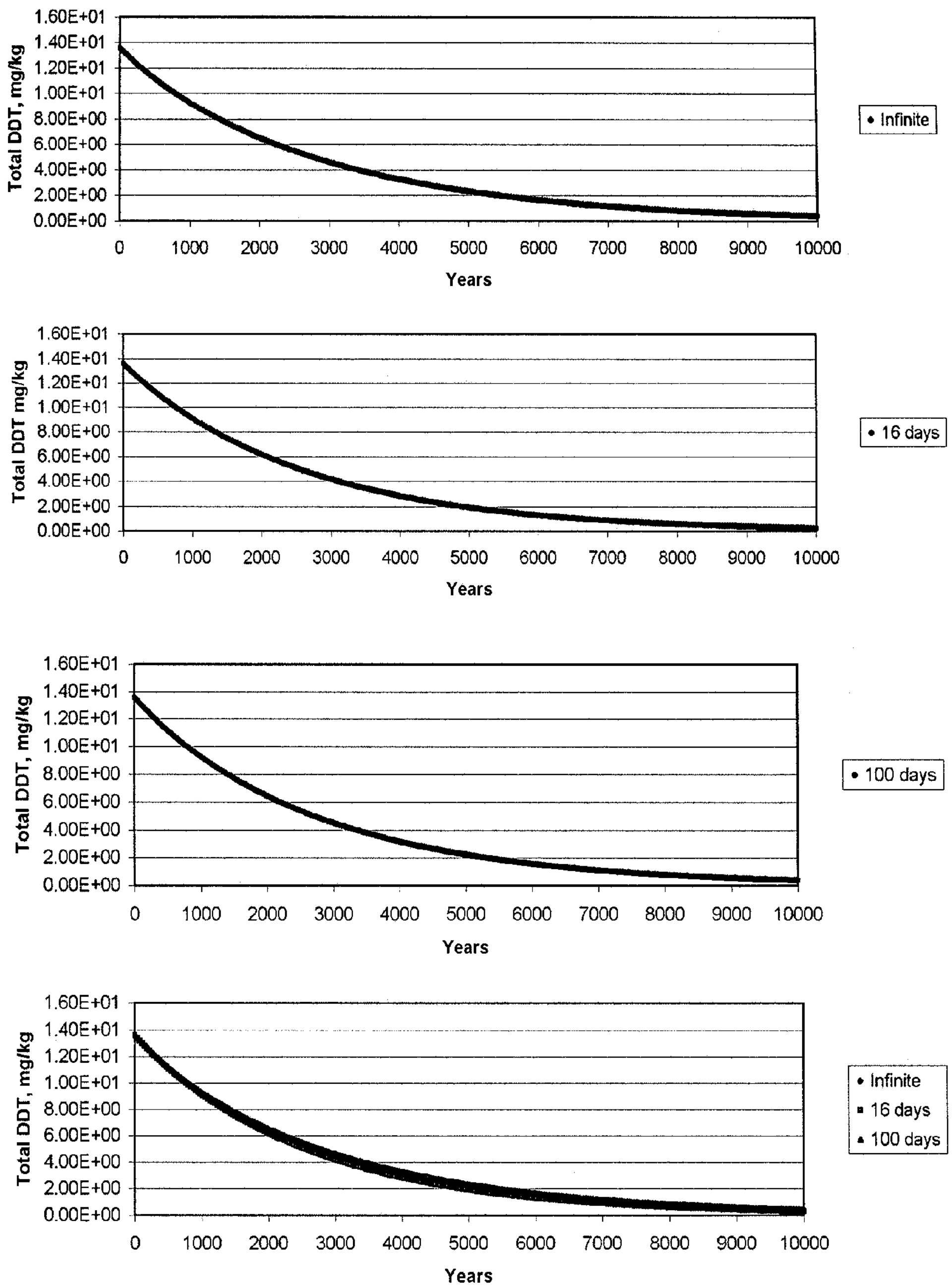


Figure D6. Comparative plots of DDT sediment concentration in the mixed layer, Station 556, showing effect of assumed degradation, no cap condition

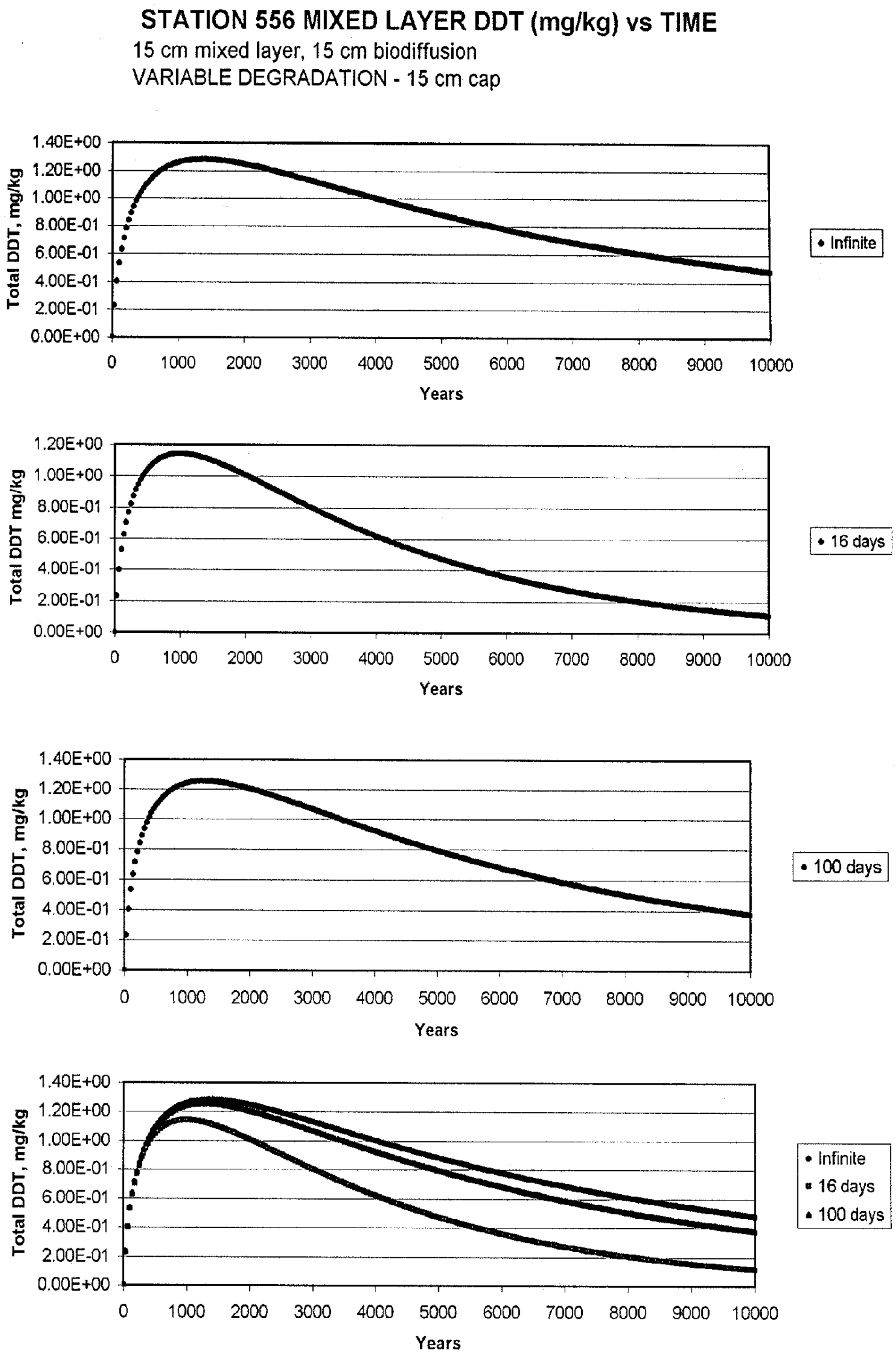


Figure D7. Comparative plots of DDT sediment concentration in the mixed layer, Station 556, showing effects of assumed degradation, 15 cm cap

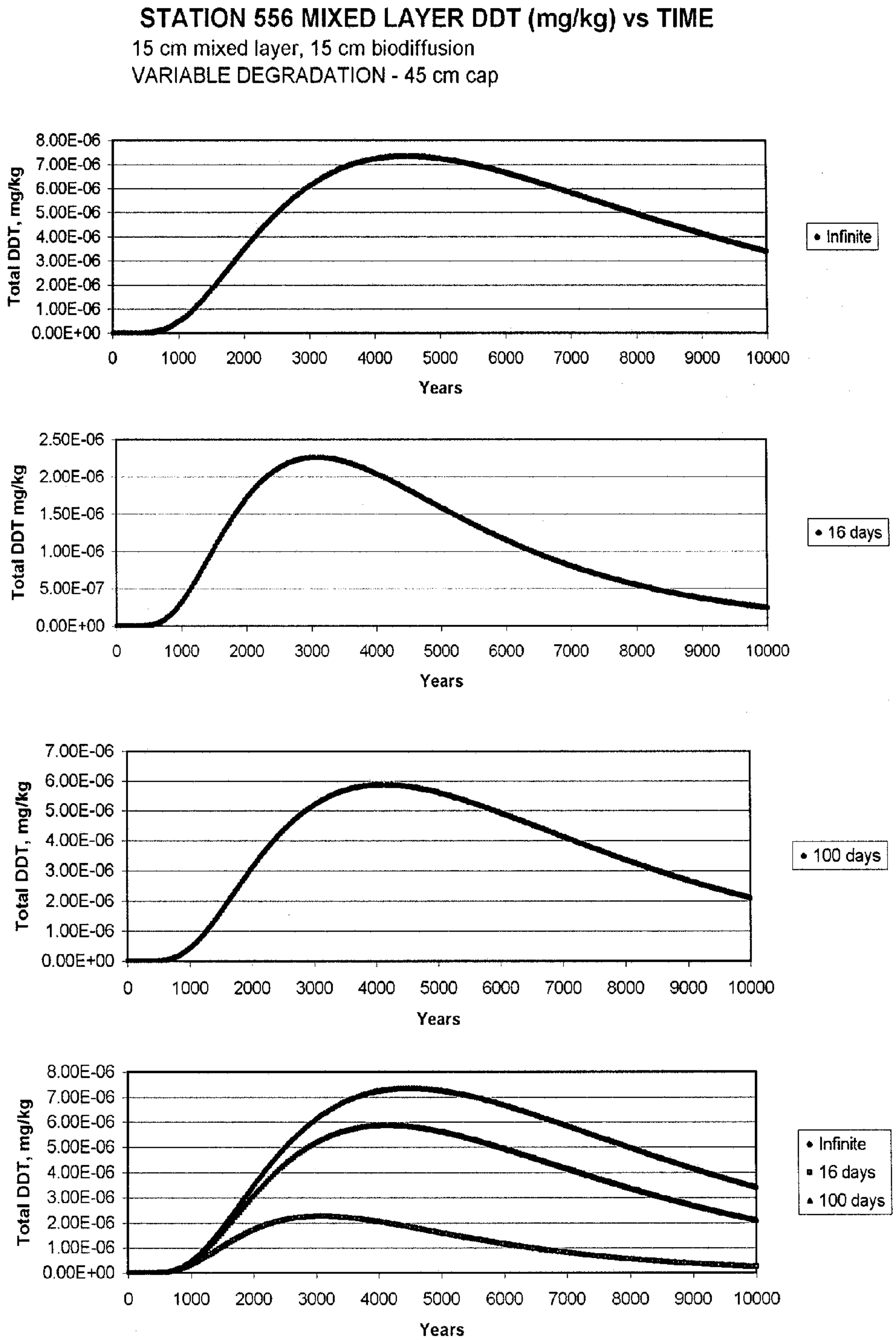


Figure D8. Comparative plots of DDT sediment concentration in the mixed layer, Station 556, showing effects of assumed degradation, 45 cm cap

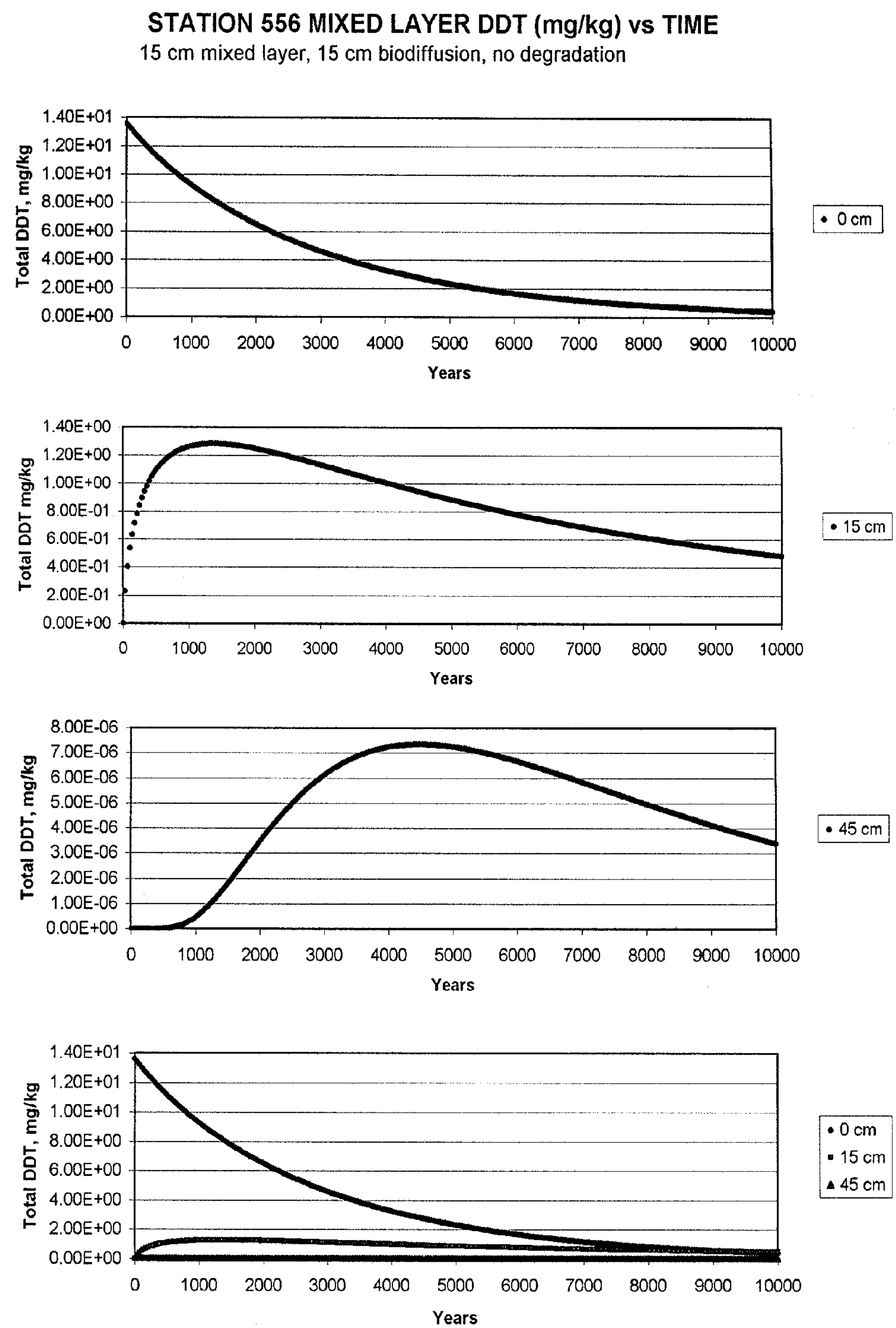


Figure D9. Plots of DDT sediment concentration in the mixed layer, Station 556, design conditions, comparing no cap, 15 cm cap and 45 cm cap

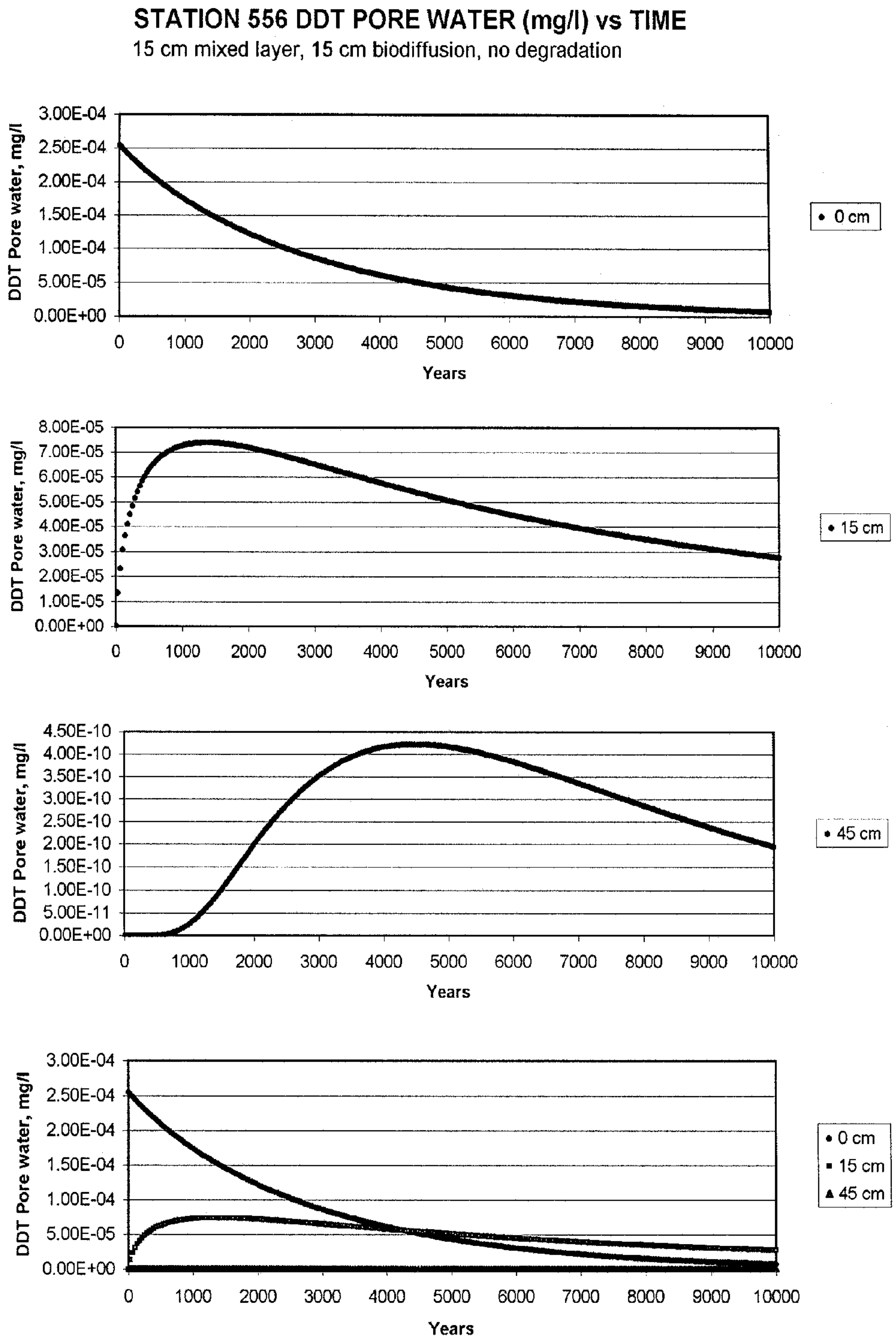


Figure D10. Plots of DDT pore water concentration in the mixed layer, Station 556, design conditions, comparing no cap, 15 cm cap, and 45 cm cap

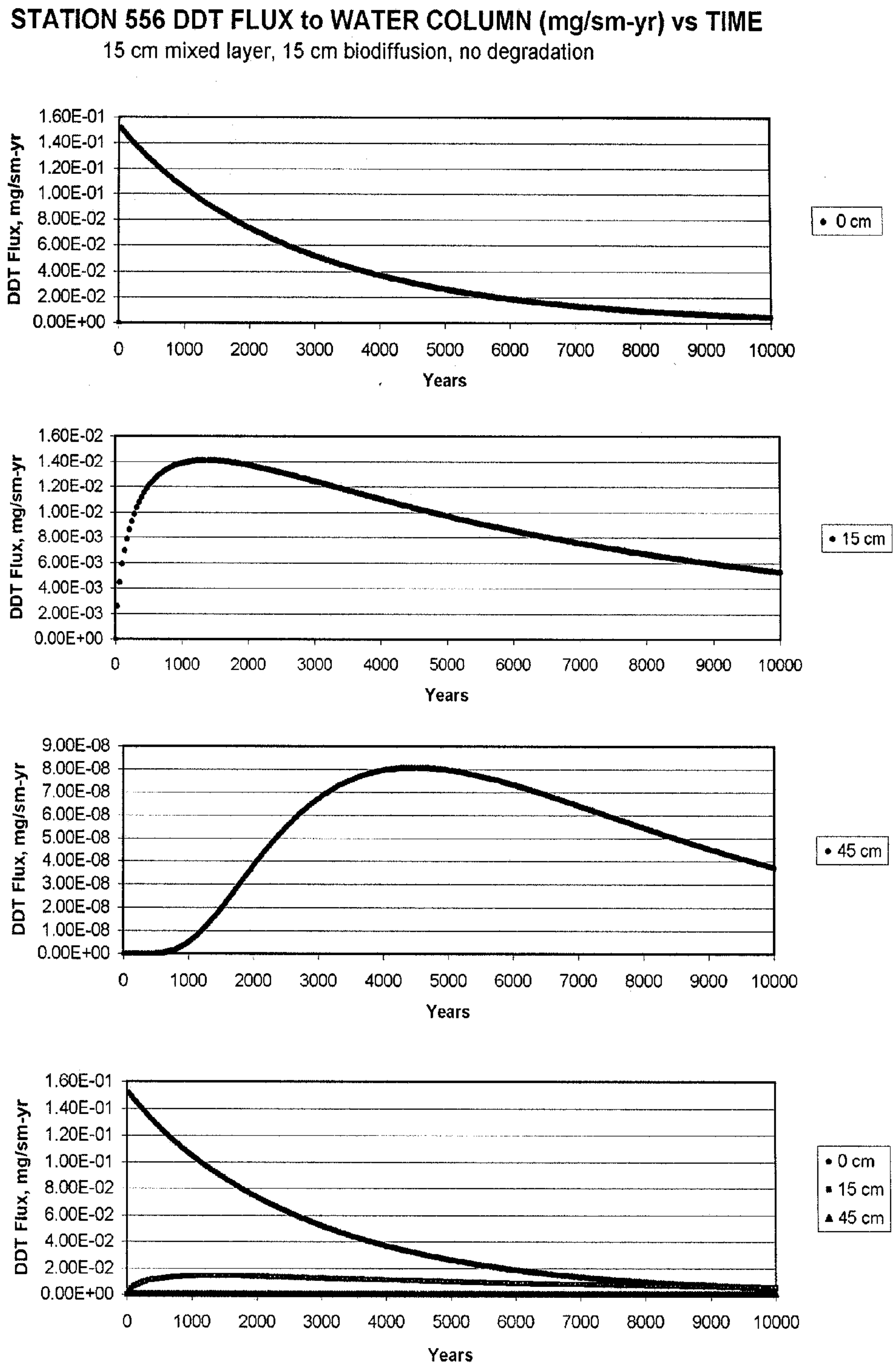


Figure D11. Plots of DDT flux to the water column, Station 556, design conditions, comparing no cap, 15 cm cap, and 45 cm cap

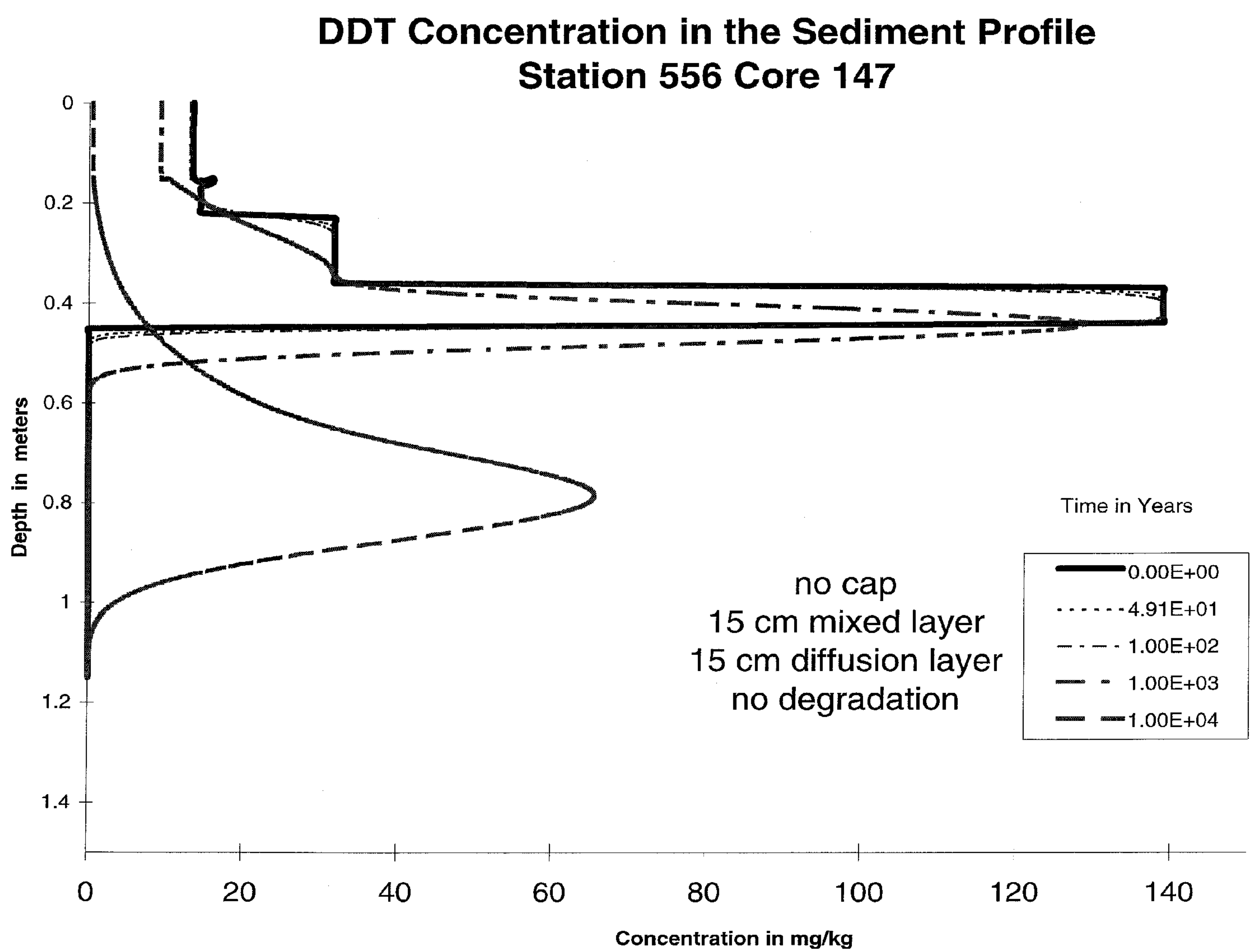


Figure D12. DDT sediment concentration profiles, Station 556, design conditions, no cap

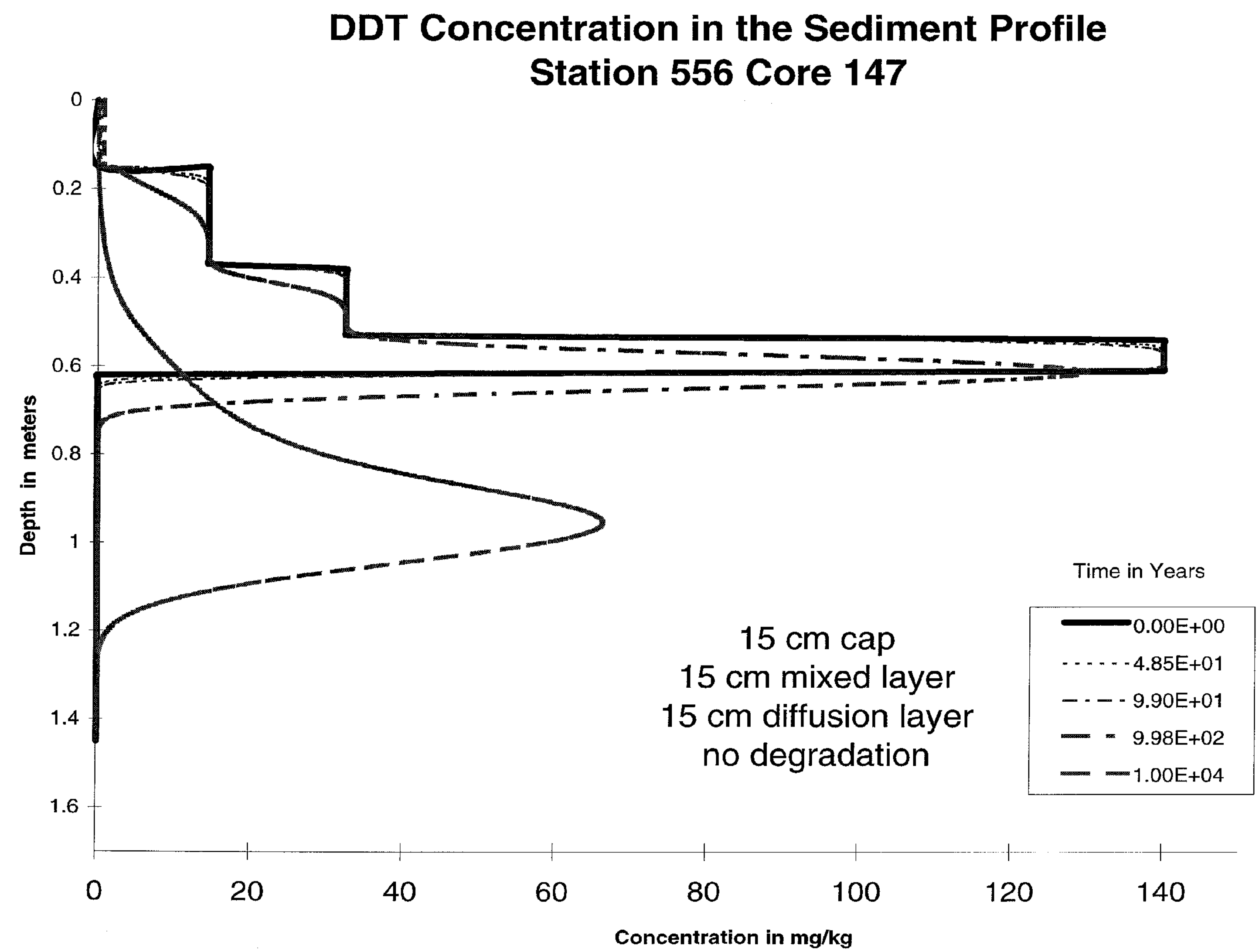


Figure D13. DDT sediment concentration profiles, Station 556, design conditions, 15 cm cap

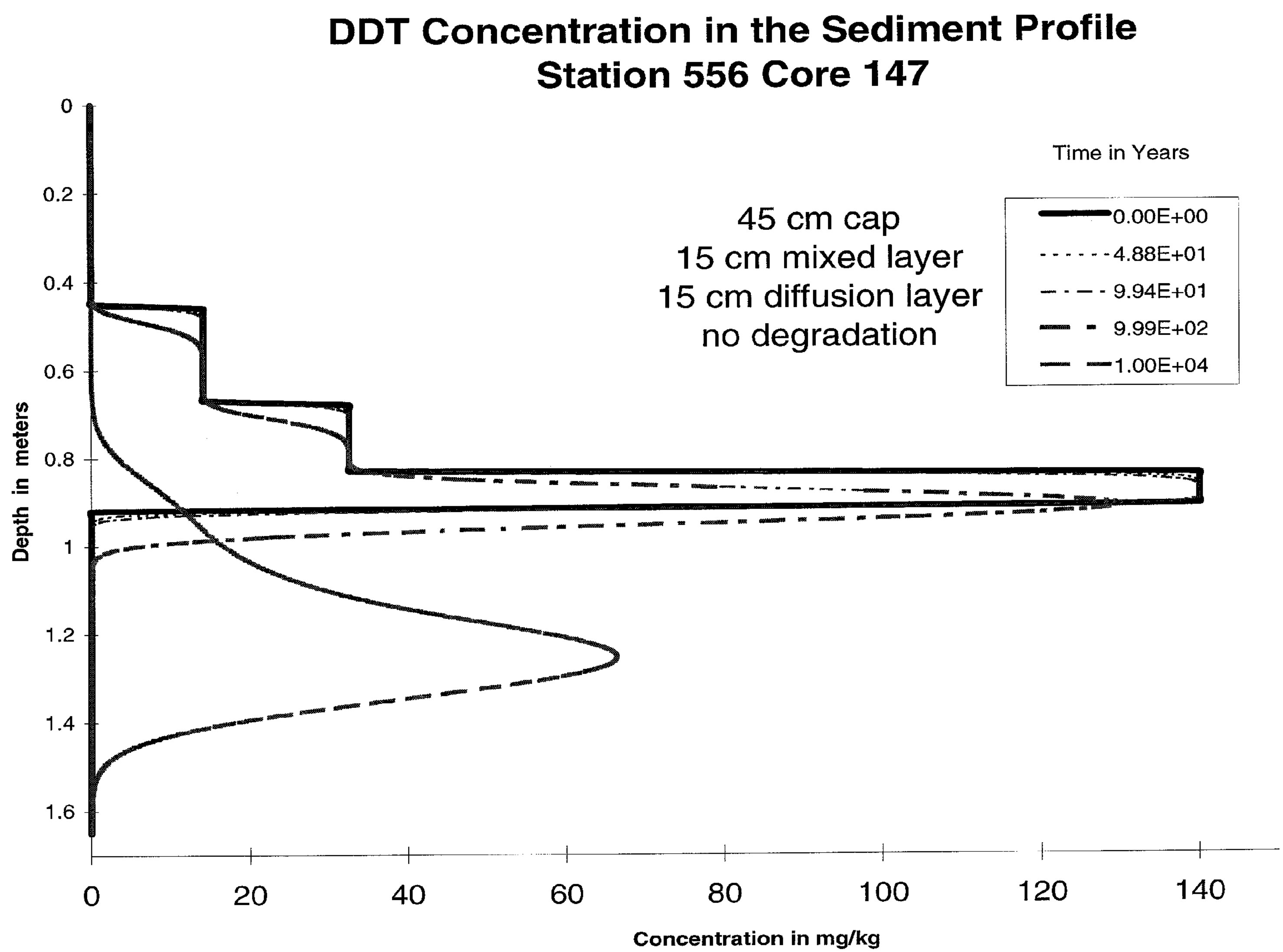


Figure D14. DDT sediment concentration profiles, Station 556, design conditions, 45 cm cap

Addendum 1 to Appendix D Cap Effectiveness Testing

The U.S. Army Engineer Waterways Experiment Station (WES) is currently evaluating options for in situ capping for Palos Verdes (PV) shelf contaminated sediments. This appendix describes one aspect of the study, laboratory testing of cap effectiveness.

Purpose of Testing

The purpose of laboratory testing of cap effectiveness was to obtain cap material specific partitioning and diffusion coefficients for DDT. The partitioning coefficient is needed to model contaminant movement from sediments into caps.

Approach

The effective diffusion coefficient for DDT in Queen's Gate cap material was measured in small diffusion tubes using radiolabeled DDT, and the partitioning coefficient was calculated from the observed effective diffusion coefficient. Effective diffusion coefficients and partitioning coefficients are defined as follows:

$$D_e = \frac{D_s}{1 + \left(\frac{\rho_s (1 - n)}{n} \right) K_d} \qquad \textbf{(D-1-1)}$$

$$K_{oc} = \frac{K_d}{f_{oc}} \qquad \textbf{(D-1-2)}$$

where

D_e = effective diffusion coefficient, cm^2/day
$D_s = D_m\, n^{4/3}$
D_m = molecular diffsion coefficient in water, cm^2/day
f_{oc} = fraction organic carbon, dimensionless
K_d = equilibrium distribution coefficient, ℓ/kg
K_{oc} = carbon normalized equilibrium partitioning coefficient, ℓ/kg
n = porosity, dimensionless
SG = specific gravity, dimensionless
ρ_s = solids density, kg/ℓ
= SG•density of water,

The specific gravity (2.74), porosity (0.87), and organic content (0.002) of Queen's Gate cap material placed in the diffusion tubes and a literature value for the DDT molecular diffusion coefficient (0.485×10^{-5} cm^2/sec, Thibodeaux 1994) were used to calculate the DDT partitioning coefficient for Queen's Gate cap material.

Radiolabeled DDT was used in order to quantitate DDT concentrations in thin sections (100 μm) of cap material. Quantitation of unlabeled DDT in such thin sections is not possible. Thin slices are required because diffusive transport of hydrophobic organics is very slow and must be measured in distances on the order of 0.1 mm when the time scale for measurement is on the order of 100 days (Di Toro, Jeris, and Ciarcia 1985).

Experimental Methods

Method Summary

The procedures of Di Toro, Jeris, and Clarcia (1985) were adapted for this study. Details of the experimental protocols are presented in the following sections. Sediment from Palos Verdes Shelf was mixed with [^{3}H] labeled dichlorodiphenyl- trichloroethane ([^{3}H]DDT) and placed in polyethylene diffusion tubes. The sediment was covered with a layer of Queen's Gate capping material, then stored at 10$\pm$ 1 degrees Centigrade. At specified time intervals, the diffusion tubes were cut using a microtome, and the microthin sediment slices obtained were analyzed for radioactivity by liquid scintillation counting (LSC). Diffusion coefficients were obtained by fitting a diffusion equation to the DDT concentration curves developed from the experimental data.

Materials and Equipment

The [^{3}H]DDT was obtained from Chemsyn Science Laboratories. The material had a specific activity of 15.2 Ci/mmol, a concentration of 1.06 mCi/mL (90:10 toluene/methanol mixture), and a radiochemical purity greater than 98%.

Instagel XF scintillation cocktail from Packard Instrument Company was used as received. A Carl Zeiss, Inc., Model HM 440E microtome was used to slice the diffusion tubes. The microtome was equipped with an automatic sample feed mechanism and an electronic monitoring system with the capability of measuring sample thicknesses in microns and sequentially counting and summing individual sediment slices. A Packard Model 307 Oxidizer was used for preparing the [^{3}H]DDT spiked sediment for LSC, and tritium activity in the spiked sediment was confirmed on a Packard Bell TRI-CARB 2500 TR, multi-channel, liquid scintillation counter. Slices obtained from individual diffusion tubes were directly analyzed by LSC according to procedures described in American Society for Testing and Materials (ASTM E 181). Background, luminescence and automatic color quench corrections were performed on all samples.

Sediment and Cap Material Preparation

Palos Verdes sediment and Queen's Gate capping material were wet-sieved through a No. 200 (0.075 mm) standard sieve. A 50-gram sample of Palos Verdes sediment was weighed into a 250-ml flask, and a syringe was used to add 95 *u*ℓ of the [^{3}H]DDT solution to the sediment. The syringe was rinsed with 95 *u*ℓ of a 50:50 toluene/methanol mixture and the rinsate was added to the flask. The spiked sediment was mixed on a shaker for 4 days. Solvent removal was accomplished by sparging the flask with air and venting volatile material through a gas absorption tube containing Ascarite to remove organic vapors and bubbling the air stream through a solution of sodium hydroxide to trap inorganics. The radiolabeled sediment was then transferred to an aluminum tray. Quintuplicate samples were removed, oxidized on a Packard Model 307 Oxidizer, then analyzed for [^{3}H] activity by LSC. Queen's Gate cap material was not spiked.

Preparation of Diffusion Tubes

Diffusion tubes were prepared as outlined in Di Toro, Jeris, and Clarcia (1985). Radiolabeled Palos Verdes sediment (1.0 mℓ) was added to the tubes. After 7 days, overlying water was removed from the tubes and 0.3 mℓ of unlabeled Queen's Gate cap material was placed on top of the sediment. The diffusion tubes were covered with parafilm wrapped stoppers, placed in a crossmatch holder, then stored at 10$\pm$ 1 degrees Centigrade.

Sampling

After 91, 146, 195, 273, 277 and 365 days, the diffusion tubes were mounted in the microtome. Overlying water was carefully removed with a pipetor and the tubes were cut into microthin (100 *u*m) slices. Distilled-deionized (DDI) water (1.5 mℓ) was used to flush each microthin slice into separate 20 mℓ scintillation vials. Instagel XF scintillation cocktail (10 mL) was added to the vials and the samples were placed on a vortex mixer for 15 seconds. An

additional 3.5 mℓ of DDI water were then added to the vials. After vortexing again for 5 seconds, the water/instagel mixture formed a stiff gel which suspended the sediment particles throughout the sample matrix. The samples were then analyzed for [^{3}H] activity by LSC.

Data Reduction

Concentration profiles showing DDT movement into the cap material for each elapsed time were prepared from the LSC data and analyzed using procedures modified from Di Toro, Jeris, and Clarcia (1985). The method involved fitting a diffusion model to the concentration profiles and determining DDT effective diffusion coefficients by optimizing the fit. The governing equation for diffusive transport is

$$\frac{\partial C}{\partial t} = D_e \frac{\partial^2 C}{\partial z^2} \qquad \textbf{(D-1-3)}$$

subject to

$$C(z,0) = C_o \qquad z>0$$

$$C(z,0) = 0 \qquad z<0$$

where z = 0 is the sediment-cap interface, all z <0 is cap material, and all z > 0 is sediment. If the diffusion tube boundaries are far enough from the interface so that an infinite spatial domain is a reasonable approximation, the solution (model equation) for the cap material region is

$$C(z,t) = \frac{C_o}{2}\, erfc\left(\frac{-z}{2\sqrt{D_e t}}\right) \qquad z < 0 \qquad \textbf{(D-1-4)}$$

the model fit was optimized with D_e as the adjustable parameter by minimizing the root mean square (RMS) given by

$$RMS = \frac{1}{n-1} \sum_{i+1}^{n} \left(Y - Y'\right)^2 \qquad \textbf{(D-1-5)}$$

Results

Average initial radioactivity measured in the spiked sediment was 4.49 X 10^6 dpm/g sediment (wet weight) and 1.59 X 10^7 dpm/g sediment computed on a dry weight basis. In comparison, the radioactivity expected from the spiking procedure was 4.47 X 10^6 dpm/g sediment (wet weight) and 1.58 X 10^7 dpm/g on a dry weight basis. Radioactivity in the samples corresponded to an average DDT concentration in the sediment of 47.7 ng/g with a range from 44.1 to 49.5 ng/g.

Figure D1-1 shows observed and fitted DDT concentration profiles for samples collected after 195, 273, and 365 days, respectively. These profiles are typical of all the data. The x-axis shows sediment depth in centimeters along the vertical length of the diffusion tubes. The y-axis is in disintegrations per minute per gram of sediment on a dry weight basis. Disintegrations per minute is a direct measurement of DDT concentration in each sediment slice. The left side of the curve corresponds to the area containing unlabeled Queen's Gate capping material and the far right area represents [^{3}H]DDT labeled Palos Verdes sediment. The curved area depicts diffusion of DDT from Palos Verdes sediment into Queen's Gate capping material.

The model equation provided excellent fits to the data, indicating that the model assumptions were closely approximated by the experimental procedures. Table D1-1 summarizes the effective diffusion and partitioning coefficients provided by the model fits.

References

American Society for Testing and Materials, (1993). "Standard general methods for detector calibration and analysis of radionuclides," ASTM *E 181*.

Di Toro, D. M., Jeris, J. S., and Clarcia, D. (1985). "Diffusion and partitioning of hexachlorobiphenyl in sediments", *Environmental Science and Technology*, Vol. 19, No. 2, pp 1169-1176.

Thibodeaux, L.J. (1996). Environmental Chemodynamics, John Wiley and Sons, New York, NY.

Table D1-1
DDT Effective Diffusion and Partitioning Coefficients for Queen's Gate Cap Material

Day	Effective Diffusion Coefficient (cm^2/day)	Distribution Coefficient (ℓ/kg)	Carbon Normalized Partitioning Coefficient (ℓ/kg)
91	2.5E-06		
146	8.2E-07		
195	2.4E-06		
273	3.2E-07		
277	9.6E-07		
365	6.6E-07		
MEAN	1.3 E-06	6.8 E05	3.7 E08
For these data, partitioning coefficients vary only with effective diffusion coefficient since porosity, bulk density, and fraction organic carbon were the same for each effective diffusion coefficient determination. Mean partitioning coefficients are therefore reported.			

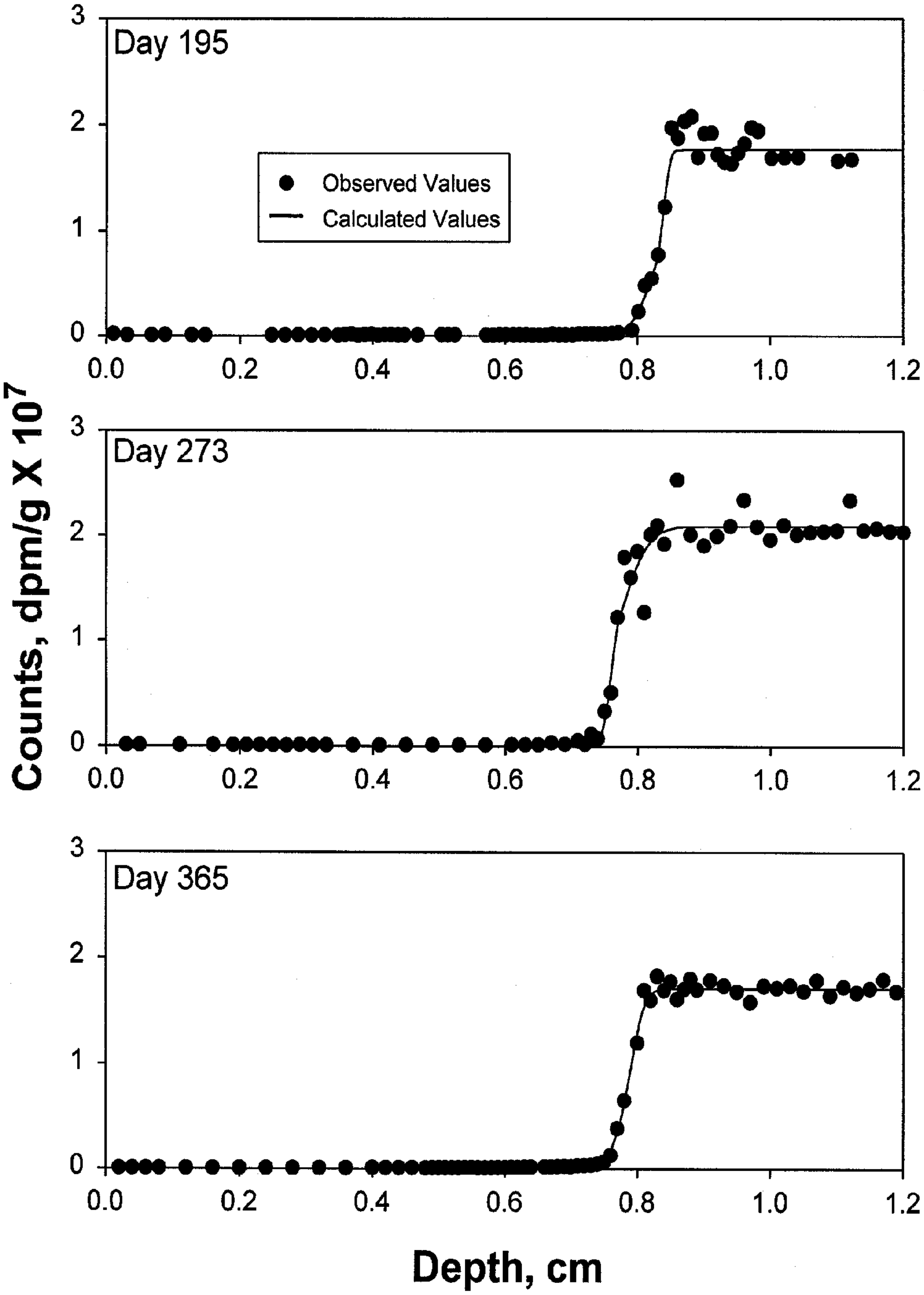


Figure D1-1. DDT concentration profiles (calculated values are from fitted diffusion model

Appendix E - Cap Placement Modeling

Introduction

The U.S. Army Engineer Waterways Experiment Station (WES) is currently evaluating options for in situ capping of Palos Verdes (PV) Shelf contaminated sediments. This appendix describes one aspect of the study, an evaluation of cap placement using several USACE computer models.

The primary objective of this effort was to determine placement methods necessary to build a cap for the conditions on the shelf, i.e., what combinations of sediment placement variables (vessel load, speed, lane spacing, etc.) would produce cap thicknesses in the range of 15 to 45 cm (0.5 to 1.5 ft) over the area of interest. The potential for resuspension of the contaminated sediments on the shelf during cap placement was also evaluated. The model results were used to develop a recommended operations plan which included placement spacings and rates of placement. It was recognized that the effectiveness of any operational approach developed based on this modeling effort would be confirmed by monitoring (see Chapter 5).

The area that would be capped (Prisms A&B) generally lies along the shelf between the 40 and 70 m depth contours (see Chapter 3). The area is on the order of several square kilometers. Due to the large area involved, it is desirable from an operational and management standpoint to define smaller areas or capping cells for operational purposes. This concept was used in this cap modeling effort.

Approach

The cap placement evaluations were based on application of several mathematical models. The Multiple Dump FATE of Dredged Material (MDFATE) model was used to predict the in situ cap geometry (thickness and extent) for various placement scenarios. The potential for resuspension of contaminated material and the dispersion behavior of capping material during placement were evaluated using the Short Term FATE of Dredged Material (STFATE) model. Potential for movement of cap material down slope and subsequent erosion of contaminated material was evaluated using a simple computer model called SURGE.

Evaluation of Cap Placement Using MDFATE

The Queen's Gate channel deepening project (referred to as the Queen's Gate project in this appendix) was considered representative of the materials potentially available for capping. As the study proceeded, the desire to make the study more generally applicable to materials dredged from other sources, specifically the sand borrow areas outside the Los Angeles/ Long Beach harbor breakwaters was expressed. A number of simulations for sand placement were therefore conducted. Additional efforts to simulate cap geometries resulting from placements by other dredges and/or other sediments could be done if required.

As noted in the cap erosion section of this report (Appendix A), two scenarios considered initially were to place material over a 2 by 2 km square or a 1 by 4 km rectangle, both centered on the White's Point outfalls (see Figure A1 and A2 in Appendix A). These generally correspond to the "modeled area" or "model grid," defined as the overall areas for which a grid was defined for the MDFATE modeling. Smaller "placement" areas, 300 m by 600 m, were designated, defined as the areas within the model grid in which cap material would be placed for the given simulation.

MDFATE Model Description

Background

MDFATE was developed under the Corps' Dredging Research Program (DRP) (Hales 1995). MDFATE was formerly known as Open Water Disposal Area Management Simulation (ODAMS) program (Moritz and Randall 1995). MDFATE is a site management tool that incorporates features of the Short Term FATE of dredged material (STFATE) model (Johnson and Fong 1993), which simulates the placement of a single load of dredged material (Figure E1), and the Long Term FATE of dredged material (LTFATE) model (Scheffner et al. 1995) which predicts the long term stability (days to years) of dredged material mounds. The MDFATE model was initially developed by Mr. H. Rod Moritz, of the USACE Portland District, and has been periodically updated and revised to accommodate a wider range of placement conditions.

STFATE is an outgrowth of the first comprehensive numerical model for predicting the fate of dredged material developed by Koh and Chang (1973). As shown in Figure E1, STFATE models conventional placement of dredged material from hoppers or barges. Conventional placement involves release of material from the hopper or barge at or slightly below the water surface through doors in the bottom of the vessel or a split hull mechanism. This practice may be termed conventional surface release and is also known as bottom dumping. With conventional placement, the vast majority of the dredged material released from a barge or hopper dredge descends rapidly to the bottom in a relatively high density

jet known as the convective descent phase. The dynamic collapse phase begins when the jet impacts the bottom or descends to a point where the density of the jet is equal to the density of the ambient water (however, this would typically occur at water depths greater than those on the PV shelf). In this phase, the more dense material immediately deposits, while the less dense particles are spread outward as a density flow when the vertical energy is transferred into horizontal momentum. Over time, the less dense material also deposits.

The LTFATE model combines hydrodynamics (waves, currents, and tides) and sediment transport algorithms to predict the stability of dredged material mounds composed of grain sizes ranging from small gravel/coarse sand down to silts and clays (see Appendix A for additional details on LTFATE sediment transport algorithms). MDFATE uses modified versions of STFATE and LTFATE to simulate multiple disposal events at one site to predict mound building and can be used to determine if navigation hazards are created, examine site capacity and mound stability, design capping operations, and conduct long-term site planning. Because of the modified LTFATE version component in MDFATE, the program can also account for cohesive and non-cohesive sediment transport, cohesive sediment consolidation and non-cohesive avalanching.

In the context of this evaluation, MDFATE was used to predict the thickness and extent of the mound (the term mound in this appendix refers to a generally circular and flat deposit of capping material accumulating on the seafloor as a result of multiple dumps or discharges of material from the dredge). The thickness and extent of a mound is important because this is equivalent to the thickness and area covered by a cap for a given disposal volume. Typical mounds normally consist of a central mound with a given thickness and side slope and a thinner “apron” of material of less dense material surrounding the central mound.

In MDFATE the suspended solids and conservative tracer portions of STFATE are removed so the modified STFATE version within MDFATE models the convective descent, dynamic collapse and passive diffusion process only. Similar to LTFATE, in MDFATE local wave and tide information can be used along with actual disposal site boundaries and bathymetry. The disposal site bathymetry can be either automatically generated (flat or sloping), or actual bathymetric data from an ASCII file can be imported.

In addition to being able to simulate the high density jet from a conventional bottom dump, MDFATE also has a module with algorithms designed to simulate the slow release of material from a barge/hopper so it may spread evenly on the bottom with a minimum amount of momentum imparted to the primary mound (i.e., particle settling). In conventional bottom dumps, the vast majority of the material descends rapidly to the bottom. With the “spreading or “sprinkling” (particle settling) method, all the vertical kinetic energy of the material coming out of the dredge (or barge) is dissipated in the upper water column, allowing the sediments to experience passive transport, diffusion and

settling of solids based on individual particle fall speed. Two spreading methods can be simulated. One method is the slow release of cap material through the slightly cracked (0.3-0.6 m) split hull of a split hull barge/hopper dredge. The second method simulates hydraulic pipeline discharge from a hopper dredge reversing its dredge pumps. In this appendix, this spreading technique is also referred to as the “particle settling mode” for purposes of modeling.

Another model similar to STFATE, the Dredging Area MOnitoring System (DAMOS) “capping” model, which is also based on the Koh and Chang (1973) model, has been proved to successfully predict the footprint of dredged material mounds placed in water with depths ranging from 90 - 132 m (295 to 433 ft) (Wiley 1995). This same model has also been found to be able to predict dredged material mound areal extent with reasonably good accuracy for mounds placed using a taut moored buoy to guide placement in water depths of about 18 m (70 ft) (Wiley 1994). For the same conditions, the DAMOS model predicts mound heights with less accuracy than it does areal extent. The DAMOS model was not used for this study because it does not allow moving vessels, nor is it able to simulate spreading behavior using discrete particle settling.

MDFATE may be roughly categorized into three primary components: grid generation, model execution, and post-processing. The initial step in executing MDFATE (and the foundation of the model) is generation of the gridded version of site bathymetry. Subsequent to grid generation, model execution consists of running the modified versions of STFATE and LTFATE which provide information to update the grid with a revised bathymetry that reflects changes resulting from placements and/or erosion. Post-processing consists of various plotting routines to present model results.

Grid Generation

Disposal site grid generation is based on a user-specified horizontal control (state plane or latitude-longitude) to create a horizontal grid. Presently, MDFATE can accommodate a grid with 40,000 nodes which will allow representation of a disposal site up to approximately 6,000 m by 6,000 m (20,000 x 20,000 ft) when using a grid nodes spacing of 30 m (100 ft). Grid corner points are specified by the user and MDFATE creates the horizontal grid based on desired grid node intervals (typical grid node spacings are 50 to 100 ft).

Vertical control is based on a user specified datum, typically mean sea level (msl) or mean lower low water (mllw). MDFATE can automatically create a uniform flat or sloping bottom based on the datum of interest, or MDFATE can overlay actual bathymetric data in ASCII form and apply it to the horizontal grid by a multi-point polynomial interpolation. Similar to LTFATE, local wave and tide information can be used along with actual disposal site boundaries and bathymetry.

Model Execution

Once grid generation is completed, MDFATE can simulate multiple disposal events (up to hundreds of events) which can extend over a period of one year. The disposal operation is broken down into individual week-long episodes during which long-term processes are simulated by the modified version of LTFATE. Within each week-long episode, the modified version of STFATE is executed for each load which simulates dredged material dumped into the water column and the resulting bottom accumulation. Cumulative results are generated for mound elevation, mound avalanching (the mound avalanches to a new, less steep side slope when a critical angle is exceeded), self-weight consolidation, and sediment transport by waves and currents.

The MDFATE version of STFATE also generates a disposal mound footprint identifying the extent of dredged material coverage for the dump, as well as mound volume and thickness. Water column currents can be accounted for as well as sloping or depressional disposal areas. Differences in material composition can be considered, and layering of different materials in the hopper can be modeled. Based on material properties, currents, etc., stripping of fines can be accounted for and an estimate of how the material accumulates on the sea floor is provided.

The LTFATE portion of MDFATE models the long-term processes affecting the created composite mound. The processes modeled include morphological changes resulting from cohesive and non-cohesive sediment erosion, non-cohesive sediment avalanching and cohesive sediment consolidation. For the sediment erosion processes, LTFATE requires hydrodynamic inputs. These data can be most easily provided from databases for tides and waves. However, the long term processes of erosion and consolidation, which could be simulated with the LTFATE module in MDFATE, were evaluated separately for this study (see Appendices A and C). The tide elevations and currents for the east, west, and Gulf Coasts were generated by an ADvanced two dimensional, finite element based hydrodynamic CIRCulation model (ADCIRC) (Hench et al. 1994). The tidal current time-series is generated from constituents contained in the ADCIRC database for the location of interest. Wave statistics from the Wave Information Study (WIS) can be used (provided by the user for the site of interest) by the program HPDSIM to generate a wave time-series and ultimately wave-induced currents. The net resulting tidal currents and wave orbital velocities are then used to drive the sediment transport portion of the model. The ADCIRC currents are also used by the STFATE model within MDFATE to generate the water column currents that affect material settling for the short-term processes. Additional details on the sediment transport algorithms used in the LTFATE portion of MDFATE can be found in Appendix A.

Output of Results

STFATE output consists of plots of mound footprint coverage and thickness of bottom accumulation. MDFATE modifies the existing bathymetric grid according to the STFATE predicted mound footprint and bottom thickness. Subsequent STFATE outputs are appended to the grid thus creating a composite mound and its associated bathymetry.

Prior Applications of MDFATE

To be effective as a planning tool, MDFATE was designed to run on personnal computers (PCS) and not to require extensive amounts of input data. To accomplish this goal, two dimensional (2D) depth averaged currents are used as opposed to 3D currents, which until very recently required a super computer and extensive data sets. MDFATE can also be used as a design tool, however, the users needs to be aware of the model limitations. At present, MDFATE is the only tool available to predict mound geometry from a series of disposals. As such, it has been used on a number of projects as described in the following section.

MDFATE has been used to simulate placement of dredged material for a number of projects, several of them involving contaminated sediments. MDFATE was used to simulate open ocean placement of clean maintenance sediments off North Carolina (Moritz and Randall 1995). In 1993, an early version of the spreading option within MDFATE was used to design placement of a cap for a contaminated sediment mound consisting of material from New York Harbor and placed in the Mud Dump site off northern New Jersey (Randall et al. 1994). MDFATE was used to simulate placement of contaminated sediments removed from New York Harbor and placed in the Mud Dump site during the summer of 1997 (Clausner et al. 1998, Lillycrop and Clausner 1998). On the west coast, MDFATE was used to design new open water placement sites for the mouth of the Columbia River (Moritz 1997).

MDFATE has also been used to simulate placement of dredged material in pits. Moreno and Risko (1995) used MDFATE to simulate placement of contaminated silt in a borrow pit in the mouth of the LA River. Clausner, Gailani, and Allison (1998) used MDFATE to simulate placement of contaminated dredged material in the North Energy Island borrow pit located in Los Angles/Long Beach Harbor.

As the above discussions show, MDFATE has been used for a number of projects. For those projects where the model results were compared to actual projects, the agreement was reasonably good, actual mound elevations were generally within 20 to 30 percent of those model predictions with overall mound geometries also showing good agreement. Considering that MDFATE uses only 2D depth averaged currents, and the amount of uncertainty in both placement locations (for some projects) and sediment characteristics, the agreement between

actual and predicted mound geometries provided by MDFATE is good. In some cases, however, a fair amount of adjusting sediment properties is required to achieve good agreement.

MDFATE Limitations

Like any numerical model, MDFATE has a number of limitations which impact the results of this study. Of primary interest are the prediction of the bottom surge which calculates how far out the apron extends. Another, somewhat related limitation is how MDFATE handles the stripping of sediments from the descending jet and advects them through the water column.

Surge Limitations. In none of the studies described above was a rigorous attempt made to correlate the MDFATE's prediction of the outer edges of the apron with the actual locations. MDFATE models the bottom collapse (bottom surge) resulting from disposal from either a bottom dumping barge or hopper dredge by computing the total energy of the bottom collapsing cloud. The energy during the bottom encounter is computed using convective descent results, e.g., the cloud velocity, radius, bulk density, etc. The total energy (sum of potential and kinetic energy) is dissipated as the bottom cloud (surge) spreads over the sea floor with the shape of an ellipsoid. When the rate of spreading due to ambient turbulence exceeds the rate of spreading due to the bottom cloud's energy, the collapse or surge phase terminates.

There is an allowance for the effect of bottom slope on the spreading of the cloud, but it has only limited application. The basic approach is to compare the bottom elevation at the centroid of the cloud's elliptical bottom with the bottom elevation at the centroids of the four quadrants of the ellipse. These four slopes are used to compute changes in the rate of spreading, which are added to the cloud dimensions computed from the basic energy algorithm discussed above. The locations of the centroids of the four quadrants are then averaged to yield the new centroid of the overall cloud.

Although there is an attempt to modify the dimensions of the bottom collapsing cloud to reflect the impact of bottom slope, as far as geometry is concerned the collapse is still assumed to occur on a flat bottom. The effect of these limitations on prediction of mound geometries was further evaluated using the SURGE model described later in this appendix.

. **Stripping Limitations.** During barge placement of sediments, a small fraction of the sediments are stripped off the descending jet and remain in the water column to be dispersed by the ambient currents. The material stripped off is most likely the finer particles. Quantifying the mass of sediments lost to the water column is difficult. Truitt (1988) provides a good summary of approximately 9 major field studies where measurements were made to estimate the volume of sediments that remain suspended in the water column. For the studies that

examined placement with hopper dredges, in water depths of up to 45 m, losses were typically less than 5 percent (Truitt 1988).

For this initial modeling effort, the stripping option was not used for the majority of the simulations. In MDFATE, when the stripping option is used, 1-3 percent of the material (by volume) is stripped off in the water column and allowed to settle at the particle settling velocity. Invoking the stripping option can considerably increase the run time for the model.

Tracking the fate of the stripped fraction and its ultimate deposition location is limited by the 2-D depth averaged currents. MDFATE does not provide an estimate of suspended sediment concentrations, it only shows the locations where sediments have settled in thickness of 0.0001 ft or more.

MDFATE Model Simulations

During the early stages of this evaluation, (June 1996- July 1997), the developer of MDFATE, Mr. H. Rod Moritz, was in the process of updating the model. This caused some delays, as bugs in the program were corrected and improved algorithms were added. Some of the earlier model runs were rerun later using corrected versions of the model. Ultimately, however, the improved version of MDFATE is thought to provide a more accurate prediction of mound geometry. In some cases the initial runs with early versions of the model were still considered valuable for the study, particularly for initial scoping of the project. The later sets of runs upon which the final recommendations are based are thought to provide the most accurate information.

Model Platform/Simulation Duration

The MDFATE model simulations were initially conducted on 75 and 100 MHZ Pentium based PCS. Final runs were made using 200 MHZ Pentium Pro PCS. Modeling placement of fine sand and silt in water depths of 30 to 90 m takes a considerable amount of time due to the slow settling velocity of the fine sand and silt particles when the spreading option was used. Therefore, fractions of the cap volume were modeled, typically about 60K to 270K m^3 (80K to 370K cy) to allow runs during business hours. Simulating conventional placement of over 230K m^3 (300K cy) placed in the water depths over the most contaminated areas, about 55 to 60 m, requires over 3 hours even on a 200 MHZ computer. Modeling placement of sediments in the spreading mode in these water depths could require over an hour just for a single load, making the modeling of large volumes of spreading material impractical for this study.

Grid Dimensions, Orientation and Bathymetry

Typically, dredged material placement was modeled over a 300 m (1,000 ft) wide by 600 m (2,000 ft) long area (Figure E2). These dimensions were judged sufficiently large to reasonably predict actual mound geometry. Note that this area is 18.6% of a 1 km by 1 km square or 4.6% of a 1 km by 4 km area. To allow viewing of the material that extended beyond the placement area, the overall grid dimensions initially modeled were 3,000 ft long by 3,000 ft wide (nominally 1 km by 1 km). Later, when the residual currents were added, the overall grid size increased to 1,700 by 2,000 m (5,600 ft by 6,700 ft).

For most simulations, a grid rotated from the horizontal to be parallel to the depth contours (Figure E3) was used for modeling, similar to the 2 by 2 km rectangle orientation shown in Figure A1 in Appendix A. For the grid to be approximately parallel to the depth contours required rotating the gird 29 degrees clockwise relative to true north.

The PV shelf has a varying bottom slope, about 1.48 deg to 1.7 deg from 30 to 70 m and from 6.1 to 7.3 deg from 70 to 100 m. Bottom slopes in the area of interest were measured at 4 points; 1 and 2 km NW of the outfalls, at the outfalls and and 1 km SE of the outfalls. The average slope for each 10 m (30 ft) increment is shown in Table E1. Because of the large variation in slopes, estimating initial cap thickness was done using a series of grids for each 10 m increment. However, while the deposit thicknesses modeled were accurate for that particular interval, the rapid changes in slopes made the thickness over adjacent depths less accurate.

To overcome this limitation, the final set of runs were made on actual site bathymetry (Figure E4), extracted from the U.S. Department of Commerce (1996) digital data available on Compact Disc (CD), from National Ocean Survey (NOS) Chart HO9591 (1976), produced at a 1:10,000 scale. Using actual bathymetry allowed a more accurate prediction of the mound thickness over areas adjacent to the placement area (assumed to be the more contaminated regions in water depths of 50 to 60 m) that have a different slope than the placement area. While the survey date, 1976, is not particularly recent, for the purposes of this modeling effort the quality of the bathymetry data should be sufficient. Differences in depths between the survey data and the present bathymetry, expected to be at most 1 to 2 m should have little impact on model results. The spikes shown in the 70 m and deeper contours are a result of the gridding process and are not actually present on site.

Tides, Residual Currents, and Waves

Modeling included the effects of tidal currents using the ADCIRC generated tidal constituent currents and elevations for the month of October.

Noble (1994) summarized the results of a PV shelf current study conducted as part of the NOAA investigations. Tidal currents do not play a large role in the residual (net current) currents experienced on the shelf. Mean currents flow northwest along the depth contours (roughly 300 degrees), for both the mid-depth and bottom currents. Mean currents for the mid-depth and bottom currents average around 10 cm/sec. For the conventional bottom placements, both the tidal currents as calculated from the ADCIRC tidal constituents and a 10 cm/sec residual current were modeled. For a typical bottom placement in water depths of 60 m, the convective jet reaches the bottom in about one minute. Thus the offset due to residual currents is small for the large majority of the material placed with conventional bottom dumping, say 10 m at most. However, the high percent of fine grained material in the Queen's Gate sediments means that the particles in the bottom surge will be in suspension for a considerable amount of time and are thus influenced by the tidal and residual current.

For a majority of the spreading mode runs, a residual current of 10 cm/sec at 300 degrees was used. During the spreading mode, the slow settling velocity of the individual particles (2.4 cm/sec for a 0.2 mm particle) and the deep depths allow a substantial displacement of the particles by the residual current. Additional discussion of the effect of particle fall speed is provided in the section on cap materials.

During conventional bottom dumping, a small fraction of the load is stripped from the convective jet. Though limited in number, investigations have estimated the volume of material lost to be a few percent at most, with typical values of 3 to 5 percent. The MDFATE model simulates stripping by removing 3 percent of the material, putting it into suspension in the upper water column and then allowing it to settle at the particle settling velocity. Stripping was not included because of the increased CPU requirements due to the slow settling speeds of the fine grained particles.

The water depths at the site are so great that the wave forces will likely have little to no effect on material placed (see Appendix A). However, for completeness, wave forces on the mound were computed based on assumed average waves of 0.9 m (3 ft) approaching from the SE (150 degrees) with a six second period.

Dredge Description

Hopper dredges were selected as the optimum equipment for capping on the PV shelf as discussed in Chapter 4 of the main text. For purposes of modeling, the Manhattan Island class dredges were assumed with a total hopper capacity of 3600 cy, and a load limit capacity of 1800 cy (1,380 m^3). The load limit capacity for a hopper dredge is less than total volumetric capacity when dredging dense sandy sediment. The dredge was assumed to have a loaded draft of 5.8 m (19.4 ft) and a light draft of 3.0 m (10.0 ft), and require an estimated 2

minutes for 90 percent of the material to exit the dredge, with all material exiting in 5 minutes. For the conventional bottom dumping model simulations, 100 percent of the material was assumed to exit in 2 minutes, and the vessel was assumed to be moving at a speed of 2 knots while the material was being released. For the spreading model simulations the dredge was assumed to be moving at a speed of 2 knots and a 20 minute discharge period for spreading was assumed. These speeds and discharge rates are considered representative of small to medium class hopper dredges, and would therefore be representative of a number of hopper dredges. Also, a slight difference in speed and discharge rate would only have a relatively small effect on the results of the model simulations.

Cap Materials

Material from the proposed Queen's Gate dredging project and borrow areas immediately outside the breakwaters were considered as cap material sources (see Chapter 3 of the main text). Review of the Queen's Gate Geotechnical Report Investigation (Sea Surveyor, Inc. 1994) indicated the material to be removed for the channel deepening is sandy silt and silty sand with some clay. Estimated volumes of each component are roughly 50 percent sand, 40 percent silt, and 10 percent clay (confirmed by CESPL). The vast majority of the sand is fine grained, with a D_{50} of about 0.1 mm. MDFATE is capable of modeling up to four separate sediment components during conventional bottom dumping. For this study, the conventional bottom dumping runs used the three components noted above, fine sand, silt, and clay. The silt was not modeled as cohesive because the amount of disturbance associated with the hopper dredging process was thought to break up the cohesive structure. The clays were modeled as cohesive. Based on suggested guidance from the MDFATE program, the values shown in Table E2 were used in the majority of the MDFATE simulations to describe the sediments. Details on how the volume fraction and deposit void ratio values were computed are provided below.

When the MDFATE model is used in the spreading (particle settling) mode, only a single sediment component can be modeled. During the spreading runs either a 0.1 mm or 0.2 mm fine sand or a 0.04 mm silt was used. While a 0.2 mm fine sand was not a significant portion of the Queen's Gate sediments, 0.2 mm sand is relatively common around inlets and the nearshore zone in Southern California and thus could be a readily available source of in situ capping sediments. This particle size is also representative of the borrow area sources immediately outside the harbor breakwaters. The settling velocity of a 0.2 mm sand particle is significantly greater than that of a 0.1 mm sand particle, 2.4 cm/sec vs 0.47 cm/sec (based on salinity of 33 parts per thousand and a temperature of 15 degrees C - fall velocities were computed assuming spherical particles using equations found in the Shore Protection Manual (1984)). This difference means that the 0.2 mm sand will fall over five times faster and therefore not be dispersed nearly as much by currents, allowing a much taller mound to be constructed for a given volume of material. Therefore some spreading runs with

the 0.2 mm sand were conducted to show the increase in mound elevations achieved with the larger material.

A similar comparison can be made between the 0.04 mm silt and 0.1 mm sand. The 0.1 mm sand will fall about 4 times faster than the 0.04 mm silt. Thus the silt will be dispersed considerably more than the 0.1 mm sand.

To better appreciate the impact of settling velocity when using the spreading mode, consider the time for a particle to reach the bottom. Assume the particle exits the dredge when its draft is 6 m (20 ft) and that the particle's initial vertical kinetic energy is dissipated by the time it reaches a depth of 12 m (40 ft). If the bottom is assumed to be at a depth of 60 m (200 ft), then the particle must fall 48 m (160 ft). A 0.2 mm sand particle will reach the bottom in 33 minutes, a 0.1 mm sand particle will reach the bottom in 2.9 hours, and a 0.04 mm silt particle will take over 11 hours to reach the bottom. A net residual current of 10 cm/sec will displace a 0.2 mm sand particle 198 m, displace a 0.1 mm sand particle 1,044 m (1 km), and displace a 0.04 mm silt particle 4 km. Because of the large distances the 0.1 mm sand and 0.04 mm silt are transported by the residual current as they fall, capping using sediments of these sizes will be difficult if not impossible because of the offset between the placement point and deposition point. These large transport distances also make it difficult to build a mound of a substantial height because of the dispersion of the finer sediments. The mound height achieved by placing the finer sediments in the spreading mode is quantified in a later section. Note that these large lateral transport distances do not occur for material placed by conventional surface release.

Changes in Sediment Volumes From Source to Final Cap

A critical aspect of cap design is the final geometry (thickness and areal extent) of the material placed on the bottom to create the cap. Estimates of the changes in volume from in-source to in-hopper to in-cap are necessary for determining the total volumes required and for estimating costs. Generally, when the designer is given the volume of capping sediment available from a navigation project, this is referred to as the in-channel (i.e., pre-dredging) volume. However, the sources for this project include navigation channels and subaqueous borrow areas, therefore the term "in-source" is used to describe the pre-dredging volume or condition. When the sediments are dredged and placed in a bottom dump barge or hopper dredge, their measured volume, referred to here as the "in-hopper" volume, will almost always be greater than the in-source volume. As material is deposited on the bottom during placement, it will occupy an initially placed volume. If materials are compressible, they will consolidate to a smaller volume over time, however, the materials available for capping are not likely to be compressible since they are primarily fine sands.

To predict the volume of sediments that will ultimately reside on the bottom at the end of the capping project, the designer must have an estimate of

how the volume of the cap material sediments will change from the in-source volume, to the in-hopper volume, and ultimately to the post-consolidation volume after placement at the disposal site.

Several terms may be used to describe basic geotechnical information on sediments. Sediments consist of solid particles (typically sand, silt and clay particles) and spaces between the particles called voids. The voids are filled with water for the saturated soils found underwater. The solids and voids are evenly distributed throughout the sediment mass, however if all the solids could be compressed together without any voids, they will typically occupy from less than half to about 2/3 of the total volume. The sediment characteristics that describe the ratios of solids to voids are the void ratio and porosity. The void ratio, e, is

$$e = V_v/V_s, \qquad (1)$$

Where V_v = Volume of voids
V_s = Volume of solids

while the porosity, n,

$$n = V_v / V_t \times 100\ \% \qquad (2)$$

where V_v = Volume of voids
V_t = Volume total

In the MDFATE program, the ratio of the solids in the hopper to the total volume in the hopper is termed the volume fraction, V_f ,

$$V_f = V_s / V_t \qquad (3)$$

During the hydraulic dredging process water is added to aid in liberating the sediments from the bottom and transporting them into the dredge head and up the suction pipe. This increases the volume of water (i.e., the voids) and reduces the volume of solid particles in a given unit volume, thus increasing the void ratio of the sediments in the hopper compared to the in situ void ratio. Once deposited in the hopper, some of the added water can be allowed to overflow the hoppers (termed overflowing), increasing the volume fraction of sediment in the hoppers. The grain sizes of the Queen's Gate sediments are sufficiently fine that overflowing the hopper will probably not result in a significant increase in hopper load. The volume fraction of the sediments in the hopper, typically ranges from about 0.2 (for sediments that are 100 percent fine grained) to 0.6 (for all coarse or medium sand). After the sediments are released from the dredge, they fall through the water column to rest on the sea floor, where they will typically have a void ratio of between 0.7 and 10.0 depending on the type of sediments. The height or thickness of the cap and the volume occupied by the sediments will be a function of the as-deposited void ratio.

The report on the Queen's Gate sediments did not list project sediment water contents or void ratios. Also, no in situ void ratio data were available for the sand borrow areas. In the absence of such data, an in situ void ratio of 0.9 (porosity of 47%), typical of silty sand, was used for the Queen's Gate material, and a void ratio of 0.7 (porosity of 41%), typical of sand, was used for the sand borrow material (Eckert and Callander 1987).

For some of the initial simulations, an assumed volume fraction of sediments in the hopper of 0.5 was used. For later simulations, the volume fraction in the hopper was reduced to 0.35 (porosity of 65%) (personnal communication with Mr. Rod Moritz, USACE Portland District). The MDFATE model runs for 0.2 mm sand, considered representative of the sand borrow areas, were made with the same in-hopper condition as that used for Queen's Gate material. The actual in-hopper volume fraction for the sand borrow material would likely be higher, so the modeling results are considered conservative.

The values for void ratio, porosity, and volumetric fraction used in the MDFATE model runs are summarized in Table E3. A small scale settling test was conducted for a sample of Queen's Gate sediments using procedures in USACE Engineering Manual 1110-2-5027. This test resulted in a void ratio of 1.39 (porosity of 58%), and was considered representative of the initially deposited porosity of the material on the bottom prior to long term consolidation. The void ratio of the in-cap Queen's Gate sediment as listed in Table E3, 1.39, is the composite of the individual void ratios of the three constituents (sand, silt, and clay shown in Table E2). An in-cap void ratio of the sand borrow material of 0.7 was used, equal to the in-source condition.

Selection of Placement Method

Most Corps capping projects (over 30) have been conducted in Long Island Sound by the New England District. These projects have used conventional bottom dumping from split hull barges to place cap material (SAIC 1995a). Some recent projects, notably the Port Newark/Elizabeth dioxin sediments capping project conducted in 1993-1994 by New York District at the Mud Dump site off Sandy Hook, NJ (Randall, Clausner, and Johnson 1994) and the Eagle Harbor, WA, Superfund project conducted by Seattle District in 1994 (Nelson, Vanderheiden and Schuldt 1994) required that the cap sediments impact the bottom at the particle settling velocity to reduce resuspension to a minimum. To achieve particle settling with the 0.4 mm sand used for the cap at the 23 m (75 ft) deep Mud Dump site during the Port Newark/Elizabeth project, the New York District required the split-hull hopper dredge to place material with the hull cracked 0.3 m (1 ft) and the hopper barge to perform direct pump-out using over the side pipes. At Eagle Harbor, where water depths ranged between 11 and 14 m (33 and 46 ft), the silty sand cap sediments were placed by washing sediments from the deck of a flat deck barge using a fire hose over the most easily resuspended sediments (containing very easily resuspended liquid creosote), or

using a split hull barge with a 0.3 m opening over the less contaminated materials. It was assumed that resuspension would be of concern for the PV shelf sediments, so the initial runs were performed with MDFATE using the spreading method of placement, and subsequent runs were made using conventional placement methods.

MDFATE Modeling Results

This section describes the results of the MDFATE simulation efforts. It begins with a brief discussion of how the mound geometry measurements were computed. This is followed by a description of some preliminary tests to determine whether the spreading option (i.e., particle settling) or conventional bottom placement is best suited for placing an in situ cap on the PV shelf. The preliminary results showed that conventional bottom placement would be much more effective, therefore the section describes the conventional bottom placement simulations. The section concludes with a discussion of how the MDFATE simulation results were applied to compute in situ cap volume requirements.

Mound Geometry and Cap Coverage Measurements

For most of the placement scenarios modeled, several different measures of mound geometry were made. Probably most straightforward is the maximum mound thickness, a calculation reported by MDFATE when the post placement mound bathymetry is subtracted from the baseline bathymetry. The maximum mound height however, is not thought to accurately predict the mound thickness over a wide area because the maximum height was often realized over just a small area, 100 m or less in diameter. Therefore, a design mound thickness was determined from each placement scenario. The design mound thickness is defined as the thickness that should be expected to be achieved over the majority of the placement area. Typically, the design thickness was the maximum thickness that covered an area at least 300 m (1,000 ft) long by 150 m (500 ft) wide, or at least half of the major dimensions of the 600 m by 300 m placement area. For example, Figure E5 which shows the mound predicted from placing an in-hopper volume of 61,900 m^3 (81,000 cy) of 0.1 mm sand over a 300 by 600 m (1,000 by 2,000 ft) area in the conventional dumping mode. For this placement, the maximum thickness is 20 cm, however this only covers an area roughly 30 m (100 ft) in diameter. The 15 cm contour covers two areas, one approximately 180 m (600 ft) in diameter, with the other about 45 m (150 ft) in diameter. The 13 or 14 cm contour (not shown) would likely meet the criteria for the design thickness. During an actual capping operation an area much larger than 600 m by 300 m is expected to be covered, and material accumulating outside a given placement area will contribute to achieving the design thickness in adjacent placement areas.

Results for Spreading Method

To determine the viability of the spreading method to produce a mound of a substantial elevation (15 cm or greater), a series of model runs with a range of grain sizes using the spreading method were made. Each run consisted of 45 loads of 1,380 m^3 (1,800 cy) each, including the voids and the solids volumes for a total of 62,000 m^3 (81,000 cy) spread over a 300 by 600 m area with a constant water depth of 60 m. The actual PV shelf bathymetry was not used because it had already been imported at a 50 ft grid spacing. The flat 60 m grid allowed a range of grid cell sizes to be easily created and used. While the cap thicknesses predicted with the flat bottom are not as accurate as they would be for the actual bathymetry, this effort was to provide rough estimates to show the relative efficiency of each grain size as capping sediment.

Spreading loads were placed for 20 minutes from a dredge with a 0.3 m (1 ft) wide cracked hull traveling parallel to the depth contours at 0.9 m /sec (1.8 knots). The dredge covered the area by traveling parallel lanes spaced 250 ft apart. Sediments tested were 0.2 mm sand, 0.1 mm sand, and 0.04 mm silt. The volume fraction in the hopper was 0.35, with an as-deposited void ratio of 0.7 assumed. This as-deposited void ratio is low for the silt, but it was used for consistency. If the silt had showed an appreciable cap thickness, the void ratio value would have been adjusted higher to a more realistic value.

During an actual capping operation, restricting the disposal of the relatively fine sediments (0.1 mm sand and 0.04 mm silt) so that disposal from a cracked hull would take a full twenty minutes would likely be difficult. These fine sediments will likely exit the dredge considerably faster, not allowing true particle settling to be achieved. To actually perform capping with these relatively fine sediments would likely require pump-out through over the side pipes or skimmers. This would likely require 35 to 40 minutes to accomplish. However, for the purposes of comparison, the 20 minute discharge time through the cracked hull is considered acceptable and required less time to run.

Table E4 summarizes the results from the spreading model scenarios. The 0.1 mm and 0.2 mm sand spreading scenarios used a square grid 20,000 ft on a side with individual grid cells 200 ft square. This large grid was required to accommodate the size of the sediment clouds created within STFATE during this scenario using particle settling. Tidal currents and a residual current of 10 cm/sec were modeled for the sand runs. The 0.04 mm silt, with only about 1/4 the settling velocity of 0.1 mm sand and 1/20th the settling velocity of 0.2 mm sand, created such large clouds in the upper water column that to allow the STFATE model portion of MDFATE to perform correctly, overall grid size had to be increased to 40,000 ft on a side with individual grid cells 400 ft square. However, the program still produced error messages because the tidal and residual currents were dispersing the silt to such an extent that insufficient material reached the bottom within the grid. Reducing the residual current to 5 cm/sec still did not allow the

model to run. Finally, eliminating the residual current allowed the model to execute with the silt using only the tidal currents.

As expected, the 0.2 mm sand provided the thickest mound, with a maximum height of 12 cm and a design height of 11 cm. Also, the vast majority (73 percent) of the sand mass was retained in the overall modeled area. Note that the percentage of mass retained in the modeled area is the volume found on the sea floor (column 4) divided by the maximum possible volume, or 36,800 m^3 (48,200 cy). Figure E6 shows the 0.2 mm sand cap contour thicknesses. The line spacing (250 ft) was insufficient to achieve a 15 cm thick mound with this option. Lowering line spacing to 200 ft, a 25 percent decrease (equal to a 25 percent increase volume placed per unit area), should be sufficient to achieve at least a 15 cm thick cap with 0.2 mm sand.

The model results for the 0.1 mm sand and 0.04 mm silt show a maximum in situ cap thickness of 1.5 cm and 0.3 cm respectively, Figures E7 and E8. These thicknesses are 12.5 % and 2.5% of that achieved with the 0.2 mm sand with only 18 % of the material remaining in the placement area for each case. The slow settling velocity combined with the tidal and residual currents resulted in wide distribution of the sediments, well beyond the placement area. Remember that the 0.04 mm silt model run had to eliminate the 10 cm/sec residual current, thus the actual spread would be even greater and the cap thickness even less than the result reported in Table E4. Based on these results, it would take 10's of millions of cubic yards to build caps with thicknesses greater than 15 cm over a 4 sq km area if the Queen's Gate sediments are placed in the particle settling mode. However, the 0.2 mm sand did create a substantial mound, with a 12 cm maximum thickness. Thus it appears that creating in situ caps on the PV shelf using 0.2 mm sand is a viable option.

There is at least one other option for using Queen's Gate or similar fine-grained sediments for in situ capping on the PV shelf. This would be to pump-out the sediments from the dredge’s hopper back down through drag arms and out through the drag heads. The drag heads could be lowered down to their maximum depth 21 - 24 m below the surface, effectively reducing the apparent depth from about 60 m to 35 - 40 m, which should significantly reduce dispersion. The MDFATE algorithms for this option have had limited testing and verification. A fair amount of additional work and perhaps some research would be required before a reliable prediction could be provided. However, this method would likely increase significantly the PV shelf in situ cap elevation by reducing the spread of fine-grained sediments such as those in the Queen's Gate project.

Because of the large amount of dispersion predicted for the 0.1 mm sand and 0.04 mm silt, MDFATE was used to model conventional disposal, i.e., where the hopper dredge is fully opened causing all the sediments to exit the dredge in a few minutes. As noted earlier, in this mode of placement the vast majority of the sediments descend quickly to the bottom in a higher density convective jet,

minimizing dispersion due to currents. While this method will likely resuspend some of the bottom sediments, the fact that the more contaminated sediments are buried beneath at least several centimeters of sediments should reduce the amount of contaminants resuspended. Also, the Corps' New England District has conducted nearly 30 capping projects using conventional bottom dumping of cap materials in even shallower water, about 20 m, and have yet to document any adverse impacts from the capping operations (SAIC 1995b).

As noted earlier, during a conventional bottom dump of the Queen's Gate sediments from a Manhattan Island class split hull dredge, all the sediments exit the dredge in 2 to 5 minutes. However, for a more direct comparison to the results from the spreading scenarios, a single model run using the same input variables used for the spreading mode runs (including a 20 minute placement duration) was made using conventional bottom release with 0.1 mm sand over the same 60 m constant depth grid used for the spreading runs. As the last row in Table E4 shows, a significant mound, with a maximum elevation of 21 cm and a design elevation of 14 cm, was created. Compared to the 1.4 cm tall mound resulting from placing 0.1 mm sand and the 0.3 cm tall silt mound created while simulating particle settling, the conventional disposal method obviously has much greater mound building potential. Therefore the focus of the remainder of the modeling effort centered on MDFATE simulations using the conventional placement mode.

Results for Conventional Placement

For the conventional bottom dumping placement scenarios, the dredges were assumed to place the material approaching the site from the east (heading west) at the rate of 4 loads per day (one load every 6 hours), which is thought to be conservative. Sediment characteristics described in Table E2 were used. Sediments were placed over a 600 m long by 300 m wide area as described earlier for each scenario listed in Table E5, except for the 45 by 60 m (150 by 200 ft) placement scenarios which were placed over a 730 m (2,400 ft) long by 300 m wide area. The center of the placement area was approximately the 55 m contour, i.e., the location of maximum contamination.

The lane spacing and number of placements per lane were varied in an attempt to create an in situ cap with the range of desired thicknesses, 15 to 45 cm. As shown in Table E5, the volume placed (in-hopper volume) ranged from 62,000 m^3 to 281,000 m^3 (81,000 cy to 367,200 cy). The mound heights and volumes after placement and the percentages of the in-hopper volumes contributing to the total area to be capped are also shown. Actual placement area varied for these simulations, but the overall grid was the same. The spacing between individual dumps on a given line and the line spacing are shown in column 2 of Table E5. The higher volumes, 180,000 m^3 (237,000 cy) and 281,000 m^3 (367,000 cy) were created by doubling the 91,000 m^3 and 140,000 m^3 (119,000 and 184,000 cy) placement scenarios, i.e., placing two loads on each placement point.

Figure E9 through Figure E13 show the contours of cap thickness superimposed on the site bathymetry along with the placement area. The cap thickness contours are in cm, while the depth contours are in meters. Typically the maximum or near maximum cap thickness contour is shown along with intermediate contours of 5 to 10 cm less than the maximum down to the 15, 10, 5, 1, 0.1, and 0.01 cm contours. The effect of the residual current can also be seen with the mound elongating in the direction of the residual current. The model often truncates the position of the 0.01 cm and 0.1 cm contour in the down current direction due to problems in accurately following the STFATE clouds of silt and clay. This is not thought to be serious problem as cap thicknesses of less than a few centimeters are not likely to provide any substantial isolation.

As can be seen from Table E5 and Figure E9 through Figure E13, the target as-placed cap thicknesses of 15 to 45 cm can be readily achieved by conventional bottom dumping of the Queen's Gate sediments. Other line and placement spacings could be developed to provide specific cap thicknesses.

It is also worth noting that the MDFATE model only predicts an average of about 65 % of the material placed actually ended up on the bottom inside the simulated grid. The remaining material either moved outside of the grid boundaries, or was still in suspension after the model reached it's time step limit. In actual practice, a much greater percentage of the material placed will reach the bottom. As noted in earlier discussions, where attempts have been made to quantify losses associated with placement from hopper dredges, losses on the order of 5 percent of less were noted. Thus the volumes and mound heights realized are likely considerably conservative.

Required Volumes for the PV Shelf In situ Cap

While the modeled volumes and the resulting as-placed cap thickness for each of the simulations are certainly of interest, the information presented above was used to compute the in-cap, in-hopper, and in-source volumes required for both potential cap material sources and the three capping scenarios proposed. The void ratios differ for the in-cap, in-hopper, and in-source conditions, and these differences in condition must be considered in calculating total required volumes. Losses of sediment due to resuspension during dredging, overflow during dredging, spread outside the total prism to be capped, and dispersion during placement must also be considered. Some losses, estimated at between a few to perhaps 10 percent or more will be realized during the dredging (spillage, overflow) and transportation (leakage) to the PV shelf site. The considerable water depths at the PV shelf site and moderate residual current provide a significant opportunity for the ambient currents to carry sediments (particularly the silts and clays) beyond the boundaries of the model, especially when the spreading option is used. Thus these sediments are "lost" from the project area from a modeling standpoint. In reality, the sediments will eventually deposit somewhere with a good chance that some of the deposition will occur on the

contaminated mound footprint because it is so large. However, some portion of the discharges will not be functioning as viable cap material within the project area.

The volume relationships for the sand borrow material would differ from Queen's Gate material because the borrow material has a larger mean grain size and contains a low fines fraction. Less material would be lost to resuspension and overflow during dredging and less material would be lost to dispersion during placement as a cap material.

Table E3 lists the values of the different variables used to describe the sediment solid/volume relationships for each of the phases in the dredging/disposal process. Correction factors to adjust the relative volumes to account for each phase of the dredging and capping process are shown in Table E6. Separate values are shown for the Queen's Gate material and the sand borrow material as sources. The table also shows the relative unit volumes for in-cap, in-hopper, and in-source, accounting for the various volume changes and losses of materials. The various volume changes and losses are described in more detail below.

In situ cap volume with no losses or spreading. The prism areas to be capped and the target capping thicknesses are described in Chapter 3. The volume of material required, assuming no losses or spreading outside the prism, was calculated as follows:

For the 45 cm thick cap over 7.6 sq km, cap volume is

7,600,000 sq km * 0.45 m = 3,420,000 m^3 (4,473,000 cy).

For the 15 cm thick cap, the cap volume is

7,600,000 sq km * 0.15 m = 1,140,000 m^3 (1,491,000 cy).

For the 15 cm thick cap over 4.9 sq km, the cap volume is

4,900,000 sq km * 0.15 m = 735,000 m^3 (961,000 cy).

These in-cap volumes must be adjusted for spreading outside the prism areas and various losses during the dredging and placement process as described below before the equivalent in-hopper and in-source volumes of capping material needed to construct the caps are determined. Table E6 summarizes the calculated unit volume adjustments.

Spread of material beyond the placement area. Since some of the material will spread outside the prisms during placement, additional material will have to be placed to achieve the design cap thickness in the prism. Typically, the

MDFATE model simulations showed that, using conventional placement, the volume in a placement area as modeled (300 by 600 m) was roughly 50 percent of the volume actually on the bottom within a distance which would be occupied by adjacent placement areas. Because the 300 by 600 m placement area is smaller than the prism to be capped, assumed to be at least 1 km wide, the actual capping operation will require the equivalent of many 300 by 600 placement areas. As noted above, the sediments from an adjacent placement area will provide some sediments to a given placement area. To extrapolate the volumes inside and outside the placement area for a full scale capping operation from the 300 by 600 m placement areas modeled, the following calculation was made.

Figure E14 shows nine 300 by 600 m placement areas, roughly equivalent to a 1 km wide by 2 km long overall prism. The gaps between the placement areas would not really occur, and they are shown merely to provide the space to list volumes that fall outside each placement area. Assume each placement area has 12 units of volume placed in it, with 50 percent of the volume remaining in the individual placement areas and 50% of the volume accumulating outside the placement area. Further assume that the 50 % of the volume outside the placement area is distributed proportionally to the perimeter length. Thus the 6 units of volume outside each placement area are distributed with 2 units each along the rectangle length and 1 unit each along the rectangle width.

The total volume of material placed is:

12 volume units/placement area x 9 placement areas = 108 volume units,

with 18 volume units accumulating outside the overall prism and 90 units inside the prism. Therefore, 90/108 or 83% of the volume placed is contributing to the cap thickness in the prism. Obviously, the additional volume outside the placement area can be more accurately quantified for a specific area and cap thickness.

For the full 4.9 and 7.6 sq km prisms, using the same logic, an additional 13.3 and 12.5%, respectively, of material placed would accumulate outside the target area. For simplicity, a conservative value of 13% was used for both prisms, with 87% of the volume placed contributing to the cap thickness in the prism. The correction factor was therefore 1/.87 = 1.15. (see Table E6).

Losses of fines during placement. During placement, a significant percentage of the finer material placed (silts and clays) will be sufficiently dispersed by the currents such that it either is moved entirely out of the immediate area or is present in such a thin layer that it is not accounted for in the MDFATE model. For the conventional bottom placements simulated for placement of Queen's Gate material, an average of about 65 percent of the material placed actually ended up in the modeled area. A larger grid and increased number of time steps to allow additional material to settle out might increase the volume of

material retained in the placement area. Model simulations for placement of 0.2 mm sand, representative of the borrow area source using spreading techniques, indicated that about 73 percent of the material placed actually ended up in the modeled area. Therefore to realize the target amount in the desired placement area, 1/.65 or 1.54 times the actual amount desired is required for placement of Queen's Gate material, and 1/.73 or 1.37 times the actual amount for sand borrow material. (see Table E6).

Conversion to Hopper volumes. The volumes required for construction of the in situ cap, adjusted for spread and losses as described above, need to be converted to in-hopper volumes to allow cost estimates to be made. The in-hopper volume is calculated as the ratio of the volume fraction in the cap to the hopper volume fraction. Values for these parameters are given in Table E3. For Queen's Gate material, the factor is 0.42/0.35 = 1.2. Although the MDFATE simulations predicting losses and spread for 0.2 mm sand, considered representative of the sand borrow material, were made with a hopper volume fraction of 0.35 (the same as that used for Queen's Gate material), this assumption was not considered appropriate for estimating the overall volumes required. Very little of the sand borrow material would be lost to resuspension during dredging and only minimal bulking in the hopper would occur (personal communications with Mr. William Pagendarm, NATCO, and Mr. Tony Risko, USACE Los Angeles District). Based on these considerations, a value of 0.54 for the in-hopper volume fraction, reflecting an approximate 9% bulking over the in-source condition, was used for the sand borrow material. With this value, the factor is 0.59/0.54 = 1.09 for the sand borrow. (see Table E6).

Losses during dredging and transportation. As noted earlier, some losses are normally associated with the dredging and transportation process including spillage (i.e., resuspension), overflow, and leakage. This loss must be considered prior to estimating the volume of in situ material requiring removal. The amount of loss was assumed to be 10 percent for the Queen's Gate material and the factor is 1/0.9 = 1.11. No loss of fines was assumed for the sand borrow material (see Table E6).

Conversion to In-source volumes. The equivalent unit in-source volume required to achieve the desired cap volumes on the PV shelf can also be calculated as the ratio of the volume fractions in each location. The in-source volume is calculated as the ratio of the volume fraction in-hopper to the in-source volume fraction. Values for these parameters are listed in Table E3. For Queen's Gate material, the factor is 0.35/0.53 or 0.66 and for sand borrow material the factor is 0.54/0.59 or 0.91 (see Table E6).

Relative Unit Volumes Considering Losses. The products of the various correction factors were used to calculate the relative unit volumes for in-cap, in-hopper, and in-source for both the Queen's Gate material and sand borrow material as shown in Table E6. Using these values, 1.0 cubic yards in the cap as

placed would require transport of 2.13 cubic yards of Queen's Gate material in the hopper, equivalent to removal of 1.56 cubic yards from the Queen's Gate source. Similarly, 1.0 cubic yards in the cap as placed would require transport of 1.72 cubic yards of sand borrow material in the hopper, equivalent to removal of 1.56 cubic yards from the sand borrow source. Note that the unit in situ volume required to build a cap is the same for the Queen's Gate and borrow materials, even though there is a smaller loss of the borrow material due to resuspension and overflow during dredging and dispersion during placement. This is due to the difference in the estimated in-cap volume fractions of the materials. The borrow sand would accumulate in the cap at a higher volume fraction as compared to Queen's Gate material, and therefore requires more solids per unit volume to build up the cap thickness.

Total Estimated Volumes. The relative unit volumes were used to calculate the total in-hopper and in-source volumes for both the Queen's Gate and sand borrow material sources. These values are summarized in Table E7.

Required line spacings and placement spacings

To achieve the designed cap thicknesses for conventional placement of Queen's Gate material, 15 and 45 cm, the line spacings and placement spacings described in Table E7 can be used. The 200 ft line spacing with a 200 ft placement spacing provided a design cap thicknesses of 16 cm, which is sufficiently close to 15 cm that is seems reasonable to use it for this conceptual design. A 45 cm cap could be constructed with 3 passes using the same spacing. As an option, the 200 ft line spacing with a 150 ft placement spacing doubled provided a design cap thickness of 48 cm, once again considered sufficiently close to the 45 cm target thickness for this conceptual design.

For placement of 0.2 mm sand using spreading techniques, the line spacing of 200 feet would be appropriate with spreading accomplished over the length of the lines corresponding to the vessel speed of 2 knots and a 20 minute discharge time period.

Design Values Summary. Table E7 summarizes the information presented in this section on conceptual design for the in situ cap for the PV shelf. The information is provided using two significant figures, considered appropriate for the uncertainty associated the MDFATE model and the sediment characteristics.

MDFATE Modeling Discussion and Conclusions

MDFATE modeling results are sensitive to the sediment characteristics. In this study, some of the required sediment data, e.g., bulk density of the in-

source sediments, were not available and had to be assumed. Also, the database of how sediment characteristics change through the dredging and disposal process is limited. It is strongly recommended that some additional data on sediment properties needed for MDFATE simulation be collected prior to more detailed studies of the PV shelf in situ cap.

While MDFATE is the most sophisticated model readily available to predict geometry of dredged material mounds placed underwater, it has had limited verification. An early version was used to predict mound geometries off North Carolina (Moritz and Randall 1995). These studies indicate the model predicted mound heights within accuracies of about 20 to 30 percent. The spreading module was used and was apparently successful for predicting particle settling cap coverage of the Port Newark/Elizabeth mound (Randall, Clausner, and Johnson 1994). Also, as noted earlier, the DAMOS model, which has the same Koh and Chang (1973) model as its basis, has predicted mound heights in shallow water and mound footprints in deep water. However, the PV shelf has a varying bottom slope which complicates simulations and reduces the expected accuracy of the predictions.

Still, with the above limitations, the predictions for cap elevations in water depths of 60 to 65 m and less are expected to be reasonably accurate. However, the assumptions on hopper load, volume fraction, time to empty, etc., all will influence the cap thickness. The influence of these variables on cap thickness could be modeled, particularly if additional data show substantial differences from the assumptions made for this study. However a number of conservative assumptions are built into the volumes required for the cap. Perhaps most conservative is the MDFATE predicted loss of 35% of the material during placement. Other studies of materials placed by hopper dredges in water depth of up to 45 m showed losses of 5 percent or less.

Some trial placements and monitoring are necessary to improve and/or validate predictions. If a specific project is selected for in situ cap placement, the model runs should be updated for a specific dredge and sediment characteristics. After a prediction of cap thickness has been made, a number of well-monitored trial placements should be made. Cap thickness monitoring should include both the dredge load characteristics (volume, percent solids) and placement data (exit time, speed and heading) in addition to the cap geometry. This information can then be used to fine tune the model predictions. This approach is discussed in Chapter 5 as a part of the monitoring program.

To limit the potential for resuspension of the contaminated sediments, it was assumed that a method to eliminate resuspension would be desired for placing the in situ cap. To eliminate resuspension, the downward momentum of the sediments placed has to be dissipated so that the sediment particles impact the bottom at the particle settling velocity. However, the MDFATE simulations using operational techniques that allow particle settling of in situ cap sediments showed

that this method is not appropriate for placing the Queen's Gate sediments on the PV shelf locations where the vast majority of contaminants are located. MDFATE predicts that the wide dispersion expected due to the deep water and currents will make it extremely inefficient (require many millions of cubic yards) to build a mound of any substantial elevation (say 15 cm) with the Queen's Gate sediments. However, 0.2 mm sand, typical of beach sand in the area, does have the potential for being placed as an in situ cap at the particle settling velocity. Concerns have been raised over placements in the deeper sections of the cap area, say 65 m-70 m or greater, where the bottom surge may continue moving down the slope and over the shelf break. Additional model simulations using STFATE and SURGE were conducted to address this issue (see discussion below).

MDFATE simulations showed that 15 to 45 cm thick in situ caps for the PV shelf can be readily created using Queen's Gate or similar sediments when they are placed in the conventional, bottom dumping mode. This method of placement allows the material to descend through the water column much more quickly, greatly reducing dispersion, meaning that much less of the capping material is carried outside of the area of interest.

Additional MDFATE simulations are recommended after a specific project has been identified and a placement mode, capping using particle settling or bottom dumping, has been decided upon. This analysis combined with additional information on sediment characteristics, dredge characteristics, desired cap thickness, area to be capped, etc., would allow more accurate predictions.

Dispersion of Cap Material Plumes

One aspect of cap placement which is of potential concern is the dispersion of the plume of suspended cap material during the cap placement process. This concern applies primarily to plume behavior with respect to turbidity or total suspended solids (TSS) concentrations in the timeframe of several hours following a given placement event.

The STFATE model, described above, is the standard method of analysis of plume dispersion for open water placement (EPA/USACE 1991 and 1998). The model was used to evaluate plume TSS as a function of time for both the hopper discrete dump and hopper spreading method of placement. Simulations were done for placement of materials at both the 40 m and 70 m water depths.

Figure E15 and Figure E16 show the TSS as a function of time for a range of water column depths for the conditions modeled. The highest concentrations occur at the water column depth within a few feet of the bottom for all runs. This reflects the suspension of cap material from the cloud as spreading progress. At water column depths approaching mid-depth, the concentrations were approximately two orders of magnitude lower than the near bottom concentrations. After a simulation time of 4 hours the model predictions show the

effect of settling with the TSS decreasing to tens of mg/l at near bottom and to less than 1 mg/l at mid depth in the water column. Based on these results, short term impacts to water quality in the immediate vicinity of the capping operations could be expected, but the effects would be temporary. These potential impacts are comparable to those resulting from ocean disposal at the LA-2 ocean disposal site (EPA 1987 and 1988).

Resuspension of Contaminated Sediment During Cap Placement

Resuspension of the contaminated sediment during placement of the cap is a potential impact considered as a part of the cap placement evaluation. The resuspension could be generated by the bottom impact and spread of the cloud or jet of material discharged from the hopper dredges. The use of hopper dredges as described above and the 40 to 70 meter water depths at the site are factors which would tend to result in dispersion and entrainment of water in the discharge, and a slower speed of descent as compared to placement methods such as barge discharge of mechanically dredged material. But the discrete discharge from the hopper for the conventional placement method would result in the advective descent of a cloud of suspended capping material. The encounter of this cloud with the bottom and the subsequent spread of the cloud laterally would have potential to generate resuspension. To evaluate the potential impact of this process, two modeling efforts were conducted. First, individual discrete discharges from the hopper dredge were modeled using the STFATE model, described above. This model generates data regarding the dimensions, densities, and velocities of the dredged material cloud during the convective descent phase. These model results were then used in a simple energy-based model called SURGE to account for the effects of bottom slope on the spread velocities and distances of spread.

Flow over the Shelf Break

A critical factor influencing the potential for EA sediment resuspension and the accuracy of MDFATE simulations is the effect of bottom slope on expected mound configuration. Also, EPA and others have expressed concerns about the bottom surge associated with placements on the deeper portions of the contaminated area. The concern is whether or not these sediments would continue to move down the steeper sections of the PV shelf, at water depths of 70 m and greater.

For the area of interest on the PV shelf with water depths greater than about 70 m, the bottom slope increases from less than 2 degrees to over 6 degrees. The angle of repose of sand mounds created by bottom dumping are assumed by MDFATE to have angles of at most 3.5 degrees and silt mounds are assumed to have slopes of at most 2.0 degrees. Dredged material mounds created in water

depths of 25 m (80 ft) or less by bottom dumping of fine grained sediments mechanically dredged have typically had maximum side slopes of about 2 degrees. Therefore the mounds created in water depths of 70 m and greater where the bottom slope exceeds the sediment's angle of repose were viewed with suspicion. It is possible that sediments conventionally bottom dumped in water depths of 70 m and greater would impact the bottom and continue to move down slope over the shelf break in a density flow. In this density flow, some of the native or existing contaminated sediments would likely be taken with the cap sediments. However, for the cases modeled, none of the sediments were placed in water depths greater than 70 m. The portion of the caps predicted to reside in water depths greater than 70 m was due to the bottom surge carrying material to those depths.

To address the MDFATE limitations in modeling the surge fate on slopes, WES developed a one dimensional model, SURGE. This model was developed for the 1997 capping project in the Mud Dump site (Clausner et al. 1997). To maximize site capacity while still retaining material in the site, New York District considered placing confinement berms at the edge of the Mud Dump site to allow placement of material closer to the site boundary. The SURGE model was used to determine the berm dimensions needed to retain the material for a given set of placement variables.

SURGE is a physics based model to aid in computing the impact of bottom slopes, but there is no spatial representation. The disposal is represented as a point source of energy that moves along specified slopes until the energy is dissipated. SURGE model calculations on the distance the surge travels can be compared to calculating the total distance a ball rolls up and down a series of slopes before it stops. Like MDFATE, SURGE is based upon an energy concept with the surge continuing to move until the total energy possessed at the moment of bottom impact is dissipated. However, in SURGE, additional considerations for bottom friction, entrainment, and settling are added along with changes in potential energy due to slopes.

The SURGE model was used to compute the distance and speed of the spread of material along the bottom for both the hopper conventional and hopper spreading method of placement and for placement of materials at both the 40 m and 70 m water depths. Results of the SURGE simulations are summarized in Table E8. The maximum distance of spread for the sand fractions of the conventional discharges was less than 100 meters. Spread distances from the centerpoint of the cloud encounter with the bottom for the silt and clay fractions for the Queen's Gate materials were approximately 100 m for the 40 m placement depth and 200 meters for the 70 m placement depth. Essentially no spreading was evident for placement of the Queen's Gate material or 0.1 mm or 0.2 mm sand using the spreading method of placement.

Based on these results, the MDFATE model predictions of cap geometry would not be significantly affected by the slopes. The results also indicate that

flow of materials downslope will be limited, and the cap materials will not continue to flow over the shelf break and potentially disturb the EA sediments on the steeper slope.

Resuspension Due to Cloud Bottom Spread

The STFATE and SURGE model results were used to evaluate the potential resuspension of EA sediments as the cloud encounters the bottom and laterally spreads. Bottom velocities generated during cap material placement were estimated using STFATE and SURGE, converted to approximate bottom shear stresses, and compared to the critical shear stress for initiation of suspension estimated by Wiberg (1994). Critical shear stresses for the in-place sediments ranged from 0.36-1.05 dynes/cm^2 for various grain sizes according to the Wiberg analysis. Assuming cap placement occurs during quiescent periods where wave action can be neglected, these shear stresses would be generated by current velocities of approximately 11-19 cm/s. The STFATE output can then be used to determine to what radius from the placement site these velocities occur from placement operations. Table E9 shows the maximum radius on the bottom for which velocities occur which produce shear stresses in the range of concern. It can be seen that the radius for which sediments are disturbed is approximately twice as great for sediments in 70 m of water compared to those at 40 m. In addition, it can be seen that the radius of potential disturbance can be reduced by over an order of magnitude by using the spreading mode of cap material placement.

It should be emphasized that these velocities will exist for only short periods of time and therefore would probably produce only minimal erosion depths. Further, the area of influence of the potential disturbance is very small as compared to the total area covered by any single hopper discharge, and the overall degree of resuspension across the capped area would be small compared to that resulting from a severe storm event which would affect the entire EA deposit on the shelf for the duration of the event. In addition, much of the suspended sediment due to cap placement would quickly mix with the cap material in suspension and settle to the bottom. Based on these results, no extraordinary management approaches to reduce the potential for resuspension during cap placement were deemed necessary. However, the spreading mode of placement could be used as a potential management approach to limit potential resuspension, at least for the initial layers of the cap material.

References

Clausner, J.E., Gailani, J.Z., Lillycrop. L.S, Rollings, M.P., Torrey, V.H., and Allison, M.C. (In Preparation). "Summer 1997 capped category II mound in the mud dump site," Draft Report for the U.S. Army Engineer New York District, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Clausner, J.E., Gailani, J.Z., and Allison, M.C. (1998). "MDFATE modeling of contaminated sediment placement in the Eastern Section of the North Energy Island borrow pit," Draft Report Prepared for the U.S. Army Corps of Engineers Los Angeles District, Los Angles, CA.

Clausner, J.E., Lillycrop, L.S., McDowell, S.E., and May, B. (1998). "Overview of the 1997 mud dump capping project," *Proceedings XVth World Dredging Congress 1998*, CEDA, Amsterdam, The Netherlands.

Eckert, J. and Callender, G. (1987). "Geotechnical engineering in the coastal zone," Instruction Report CERC-87-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

EPA. (1987). "Environmental Impact Statement for Los Angeles/ Long Beach (LA-2) Ocean dredged material disposal site, site designation," U.S. Environmental Protection Agency, Region 9, San Francisco, CA.

EPA. (1988). "Final Environmental Impact Statement for Los Angeles/ Long Beach (LA-2) Ocean Dredged Material Disposal Site Designation," U.S. Environmental Protection Agency, Region 9, San Francisco, CA.

Hales, L. (1995). "Accomplishments of the Corps of Engineers dredging research program," *Journal of Coastal Research*, 11(1), pp 66-88.

Hench, J.L., Luettich, R.A., Jr., Westerink, J.J., and Scheffner, N.W. (1994). "ADCIRC: an advanced three-dimensional circulation model for shelves, coasts, and estuaries - Report 6 - development of a tidal constituent database for the Eastern North Pacific," Dredging Research Program Technical Report DRP-92-6, U.S. Army Engineers Waterways Experiment Station, Vicksburg, MS.

Johnson, B.H., and Fong, M.T. (1993). "Development and verification of numerical models for predicting the initial fate of dredged material disposed in open water - Report 2 - theoretical developments and verification results," Dredging Research Program Technical Report DRP-93-1, U.S. Army Engineers Waterways Experiment Station, Vicksburg, MS.

Koh, R.C.Y. and Chang, Y.C. (1973). "Mathematical model for barged ocean disposal of wastes," Technical Series EPA 660/2-73-029, U.S. Environmental Protection Agency, Washington, DC.

Lillycrop, L.S. and J.E. Clausner. (1998) "Numerical modeling of the 1997 capping project at the MUDS site," *Proceedings XVth World Dredging Congress 1998*, CEDA, Amsterdam, The Netherlands.

Moreno, J.D., and Risko, A.J. (1995). "Borrow pit capping," Draft Report, Navigation Section, U.S. Army Engineer District, Los Angles, Los Angeles, CA.

Moritz, H.R. and Randall, R.E. (1995). "Simulating dredged-material placement at open-water disposal sites," Journal of Waterway, Port, Coastal, and Ocean Engineering, Vol. 121, No. 1, ASCE.

Moritz, H.R. (1997). "Management of ocean dredged material disposal sites at the mouth of the Columbia River," *Proceedings of the Western Dredging Association Eighteenth Technical Conference and Thirtieth Annual Texas A&M Dredging Seminar,"* Center for Dredging Studies, TAMU, College Station, TX, pp119-139.

Nelson, E.E.,Vanderheiden, A.L., and Schuldt, D. (1994). "Eagle Harbor Superfund Project," *Proceedings of Dredging '94,* ASCE, New York, NY, pp 1122-1131.

Noble, M. (1994). "Circulation patterns over the palos verdes shelf and upper slope, Appendix H, Predictive modeling of the natural recovery of the contaminated effluent-affected sediment, Palos Verdes Margin, Southern California," United States Geological Survey, Menlo Park, CA.

Randall, R.E., Clausner, J.E., and Johnson, B.H. (1994). "Modeling cap placement at New York Mud Dump Site," *Proceedings of Dredging '94,* ASCE, New York, NY, p.1295-1304.

SAIC. (1995a). "Confined aquatic dredged material disposal: a review of cap placement," Science Applications International Corporation (SAIC) report No. 329, submitted to New England Division, US Army Corps of Engineers, Waltham, MA.

SAIC. (1995b). "Sediment capping of subaqueous dredged material disposal mounds: an overview of the New England experience 1979-1993," Science Applications International Corporation (SAIC) report, contribution #95, submitted to New England Division, US Army Corps of Engineers, Waltham, MA.

Sea Surveyor, Inc. (1994). "Queen's Gate Dredging - Geotechnical and chemical investigation," Port of Long Beach, CA.

Scheffner, N.W., Thevenot, M.M., Tallent, J.R. and Mason, J.M. 1995. "LTFATE: A model to investigate the long-term fate and stability of dredged material disposal sites; user's guide," Dredging Research Program Instruction Report DRP-95-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Shore Protection Manual (1984). U.S. Government Printing Office, Washington, DC.

Truitt, C.L. (1988). "Dredged material behavior during open water disposal," Journal of Coastal Research 4(3), 389-397.

United States Department of Commerce (1996). "User's guide for CD-Rom data sets marine trackline geophysics and hydrographic survey data," 2 Compact Discs, National Oceanic and Atmospheric Administration, National Geophysical Data Center, Boulder, CO.

Wiley, M.B. (1994). "DAMOS capping model verification," Science Applications International Report No. SAIC-91/7603&C95, Contribution #89, U.S. Army Engineer Division, Waltham, MA.

Wiley, M.B. (1995). "Deep water capping," Science Applications International Report No. SAIC-91/7609&C96, Contribution #98, U.S. Army Engineer Division, Waltham, MA.

Table E1
Palos Verdes Shelf - Bottom Slopes for a Range of Depths

Depth Range	Average Slope Decimal (Degrees)
30- 40 m (98-131 ft)	0.0245 (1.40°)
40-50 m (131-164 ft)	0.027 (1.55°)
50-60 m (164-197 ft)	0.030 (1.72°)
60-70 m (197-230 ft)	0.034 (1.95°)
70-80 m (230-262 ft)	0.107 (6.11°)
80-90 m (262-295 ft)	0.129 (7.35°)
90-100 m (295-328 ft)	0.127 (7.24°)

Table E2
Sediment Characteristics Used in MDFATE Simulations

Sediment Type	Specific Gravity	In-Hopper Volume Fraction	Grain Size (mm)	Settling velocity (cm/sec)	In-Cap Deposit Void Ratio	Cohesive	Stripped During Descent
Conventional Placement							
Fine Sand	2.70	0.175	0.10	0.47	0.7	N	N
Silt	2.70	0.140	0.04	0.0075	1.6	N	N
Clay	2.70	0.035	0.003	0.00042	4.60	Y	N
Spreading Placement							
Silt	2.70	0.35	0.04	0.12	0.7	N	N
Fine Sand 0.1mm	2.70	0.35	0.10	0.47	0.7	N	N
Fine Sand 0.2mm	2.70	0.35	0.20	2.4	0.7	N	N

Table E3
Sediment Volume Parameters Used in MDFATE Modeling

Location	Void Ratio (e)	Porosity (n)	Volume Fraction (V_f)
Queen's Gate			
In-Source[1]	0.9	47 %	0.53
In-Hopper	1.86	65%	0.35
In-Cap	1.39	58%	0.42
Sand Borrow			
In-Source	0.7	41 %	0.59
In-Hopper	1.86	65%	0.35[2]
In-Cap	0.7	41%	0.59

[1] In-source sediment volume parameters are not used in the MDFATE simulations, but are required to determine total in-source volumes needed for construction. They are presented here for completeness.

[2]The value of 0.35 for in-hopper V_f for the sand borrow was used in the MDFATE model simulations as a conservative assumption. However, a value of 0.54 for in-hopper V_f was used for estimates of the total volumes and cost estimates due to absence of fines and the coarser size of the sand in the borrow material.

Table E4
Mound Geometry Value Results with Spreading Option and Conventional Placement

Sediment Grain Size	Maximum Mound Ht	Design Mound Ht	Sediment Volume Remaining in Grid	Maximum Possible Sediment Volume in Grid	Percent of Solids Placed Remaining in Model Grid[1]
Spreading Option					
0.2 mm sand	12 cm	11 cm	27,000 m^3 (35,000 cy)	36,800 m^3 (48,200 cy)	73
0.1 mm sand	1.5 cm	1.2 cm	6,600 m^3 (8,600 cy)	36,800 m^3 (48,200 cy)	18
0.04 mm silt	0.3 cm	0.2 cm	6,700 m^3 (8,700 cy)	36,800 m^3 (48,200 cy)	18
Conventional Placement					
0.1 mm sand	21 cm	14 cm	36,000 m^3 (47,000 cy)	36,800 m^3 (48,200 cy)	98

[1] Model grid refers to the overall defined grid for the given simulation.

Table E5
MDFATE Predictions for In situ Cap Design Values for Conventionally Placed Queen's Gate Sediments

Hopper Volume Placed	Placement Scenario Placement Spacing/Line Spacing	Max Mound Height	Design Mound Ht	Maximum Potential Volume in Site	Volume Predicted on Site	Percent Mass Retained on Site
62,000 m^3 (81,000 cy)	75 m/75 m (250 ft/250 ft)	13 cm	10 cm	51,000 m^3 (68,000 cy)	34,000 m^3 (44,000 cy)	64 %
91,000 m^3 (119,000 cy)	60 m/60 m (200 ft/ 200 ft)	19 cm	16 cm	76,000 m^3 (99,000 cy)	50,000 m^3 (66,000 cy)	67 %
140,000 m^3 (184,000 cy)	45 m/60 m (150 ft/200 ft)	27 cm	23 cm	117,000 m^3 (154,000 cy)	78,000 m^3 (102,000 cy)	67 %
180,000 m^3 (237,000 cy)	60 m/60 m x 2 (200 ft/200 ft x2)	38 cm	34 cm	152,000 m^3 (199,000 cy)	100,000 m^3 (133,000 cy)	67 %
281,000 m^3 (367,000 cy)	45 m/60 m x 2 (150 ft/200 ft x2)	51 cm	48 cm	235,000 m^3 (307,000 cy)	150,000 m^3 (200,000 cy)	65 %

Table E6
Sediment Volume Relationships

	Queen's Gate Source		Borrow Area Source	
Location	Factor	Relative Volume Occupied	Factor	Relative Volume Occupied
In-Cap Unit Volume		**1.0**		**1.0**
Loss due to spread outside prism	1.15		1.15	
Loss of Fines during placement	1.54		1.37	
Convert in-cap to in-hopper volume	1.2		1.09	
In-Hopper Unit Volume		**2.13**		**1.72**
Loss of fines during dredging	1.11		1.00	
Convert in-hopper to in-source volume	0.66		0.91	
In-Source Unit Volume		**1.56**		**1.56**

Table E7
Summary of In situ Cap Design Values

	Option 1	Option 2	Option 3
Prisms Capped	A+B	A+B	A
Prisms Area	7. 6 sq km	7.6 sq km	4.9 sq km
Initial Cap Thickness	45 cm	15 cm	15 cm
Total Volume In-Cap	3,420,000 m^3 (4,473,000 cy)	1,140,000 m^3 (1,491,000 cy)	735,000 m^3 (961,000 cy)
Queen's Gate Source			
Total Hopper Volume Required	7,285,000 m^3 (9,527,000 cy)	2,428,000 m^3 (3,176,000 cy)	1,566,000 m^3 (2,047,000 cy)
Total In-Source Volume Required	5,335,000 m^3 (6,978,000 cy)*	1,778,000 m^3 (2,326,000 cy)	1,147,000 m^3 (1,499,000 cy)
Conventional Bottom Dumping Placement Spacing/Line Spacing	45 m/60 m x 2 (150 ft/200 ft x2)	60 m/60 m (200 ft/200 ft)	60 m/60 m (200 ft/200 ft)
Borrow Area Source			
Total Hopper Volume Required	5,882,000 m^3 (7,694,000 cy)	1,961,000 m^3 (2,565,000 cy)	1,264,000 m^3 (1,653,000 cy)
Total In-Source Volume Require	5,335,000 m^3 (6,978,000 cy)	1,778,000 m^3 (2,326,000 cy)	1,147,000 m^3 (1,499,000 cy)
Spreading Placement Line Spacing	200 ft	200 ft	200 ft

* The available in-source volume from Queen's Gate is approximately 6 million cubic yards. If a limit on navigation dredging volume results in a shortfall of material to construct the cap, the balance could be taken from overdredging in the Queen's Gate channel or from the sand borrow source.

Table E8
Summary of SURGE model Results Showing Distance of Spreading

Scenario				Spreading Distances and Times			
Material	Dumping Mode	Water Depth	Fraction	Down Slope Distance, m	Down Slope Time, sec	Up Slope Distance, m	Up Slope Time, sec
Queen's Gate	Conventional	40 m	Sand	37	40	37	40
			Silt	64	90	64	90
			Clay	92	170	92	170
			Fluid	116	312	114	308
		70 m	Sand	81	100	59	70
			Silt	115	160	92	130
			Clay	216	420	152	290
			Fluid	277	779	195	547
	Spreading	40 m	Fluid	10	33		
		70 m	Fluid	14	57		
0.1-mm Sand	Spreading	40 m	Fluid	10	33		
		70 m	Fluid	15	59		
0.2-mm Sand	Spreading	40 m	Fluid	10	33		
		70 m	Fluid	15	59		

Table E9
Summary of Radius of Potential Resuspension Due to Cap Placement

Water depth / condition	Radius of potential resuspension at 1.05 dynes/cm^2	Radius of potential resuspension at 0.36 dynes/cm^2
70 m / discrete, upslope	177 m	191 m
70 m / discrete, downslope	254 m	271 m
40 m / discrete, upslope	106 m	113 m
40 m / discrete, downslope	106 m	114 m
70 m / spreading	12 m	14 m
40 m / spreading	9 m	9 m

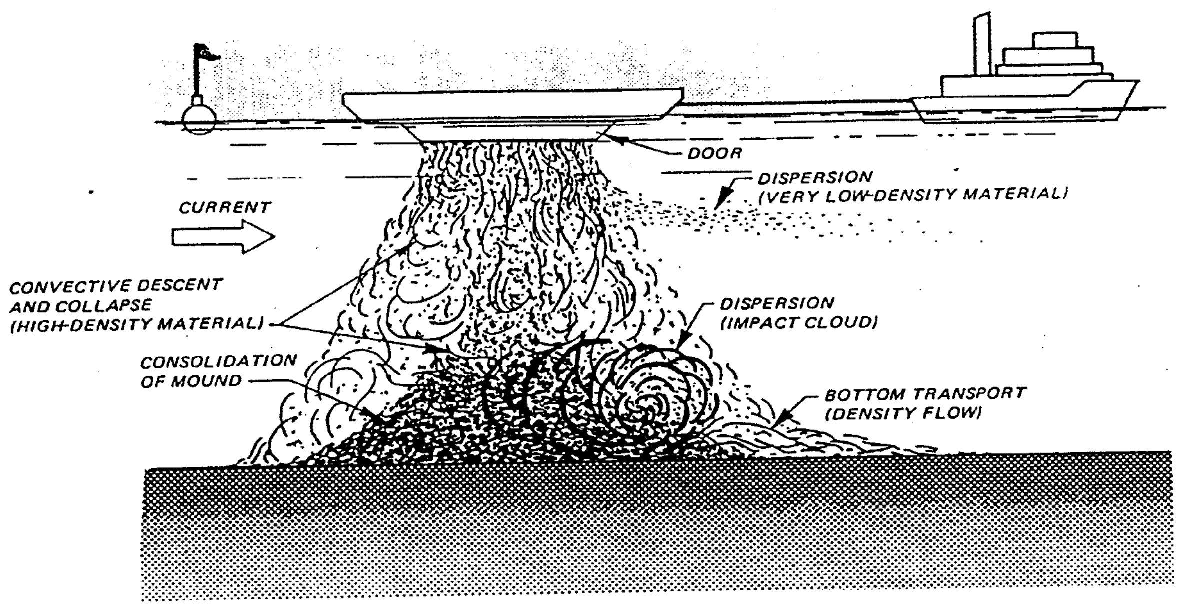


Figure E1. Processes modeled by STFATE.

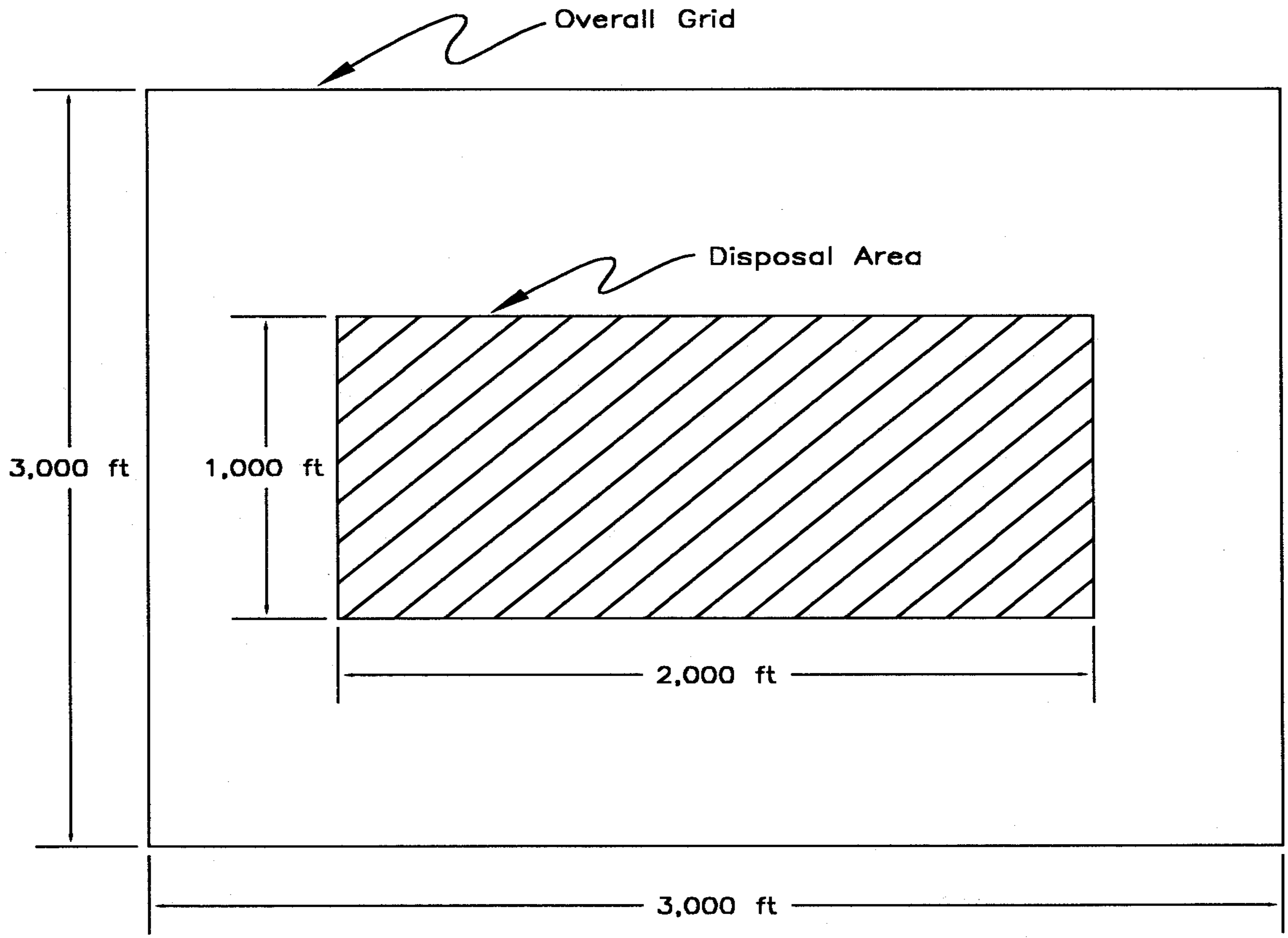


Figure E2. Grid dimensions used for many MDFATE runs

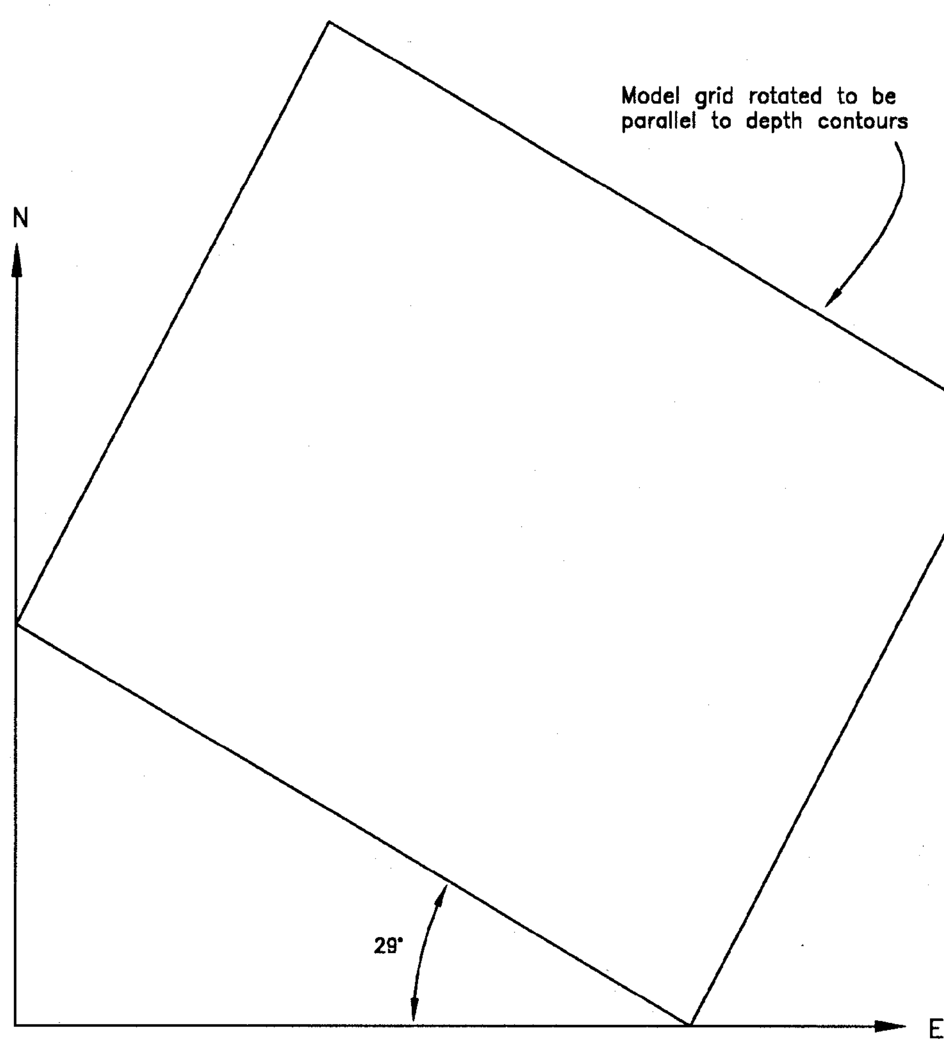


Figure E3. Rotated grid , parallel to depth contours

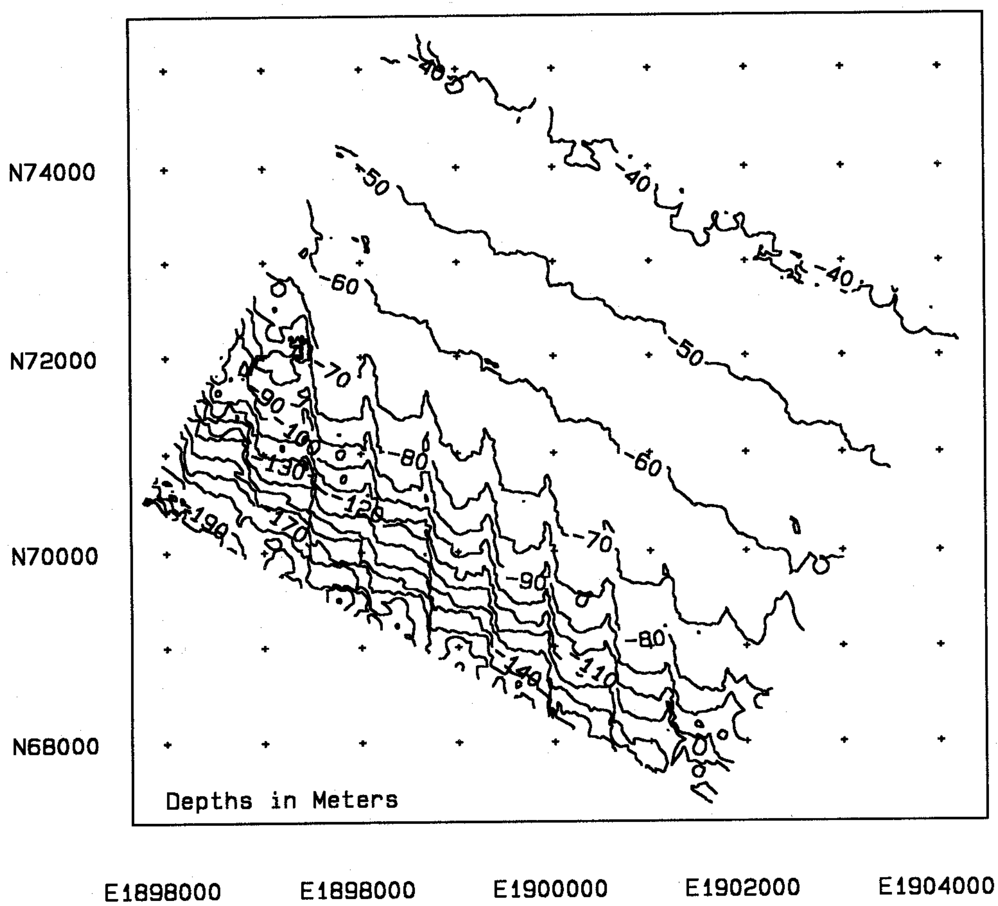


Figure E4. PV shelf bathmetry (depths in meters mllw) from NOS chart HO9591 (1976), as adapted for use by MDFATE

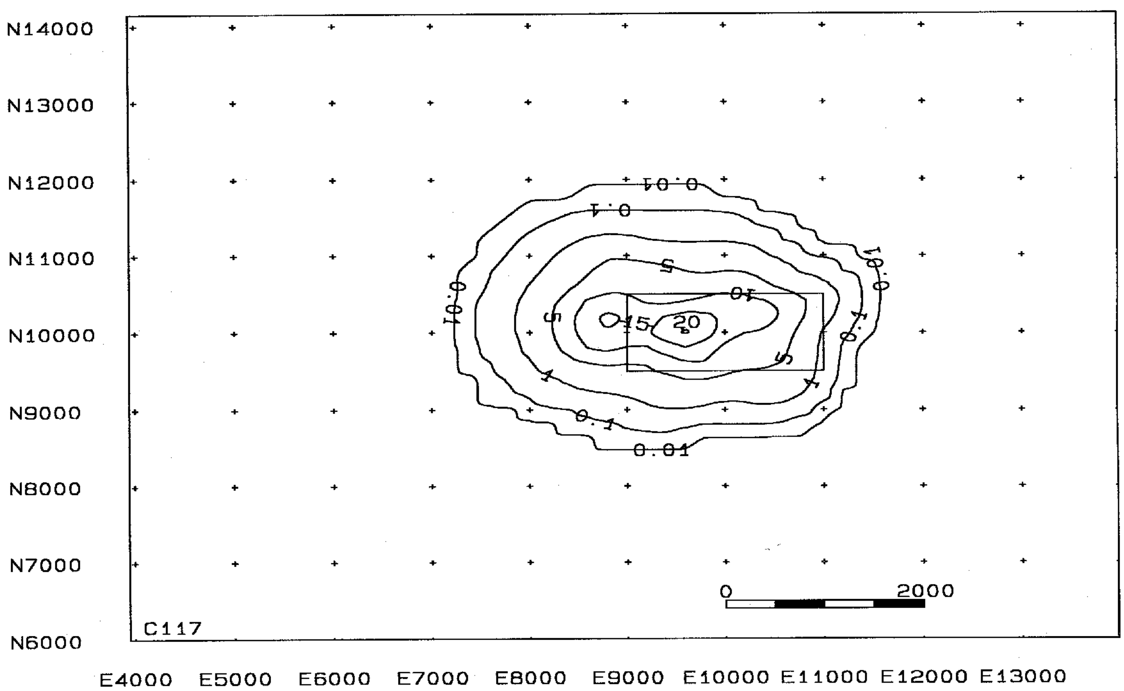


Figure E5. Example in situ mound resulting from conventional bottom dumping of 81,000 cy of 0.1 mm sand in 60 m of water

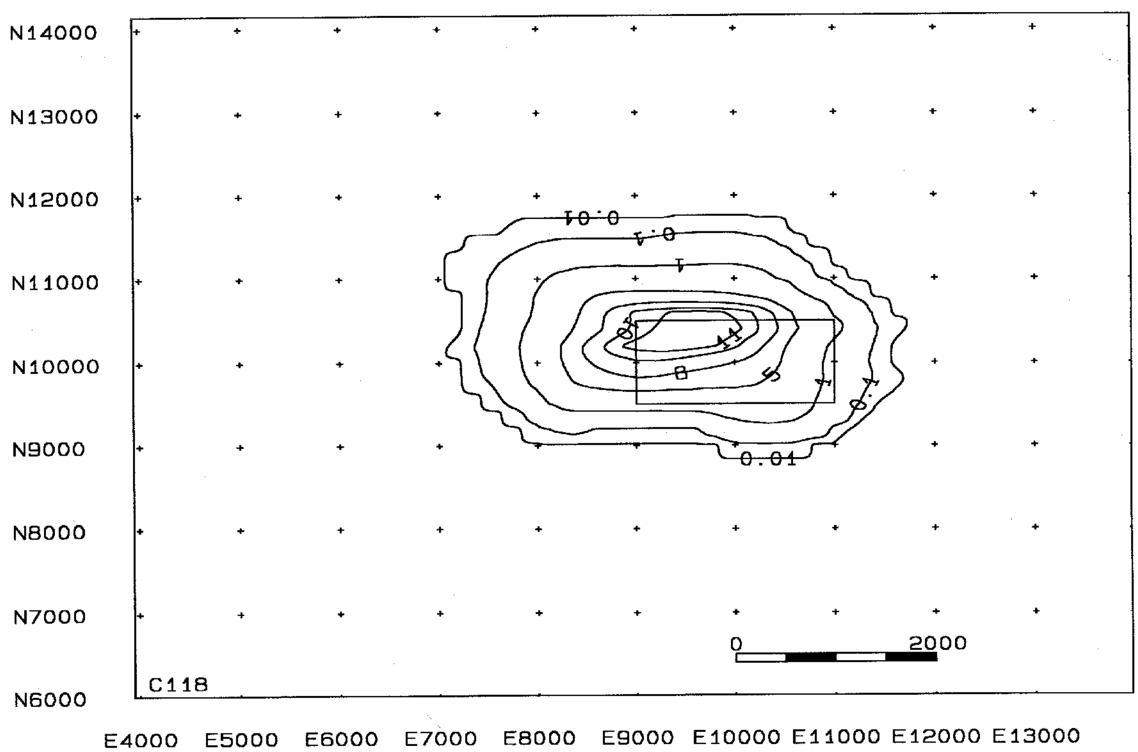


Figure E6. PV shelf in situ cap thickness contours from placing 0.2 mm sand in the spreading mode in 60 m of water

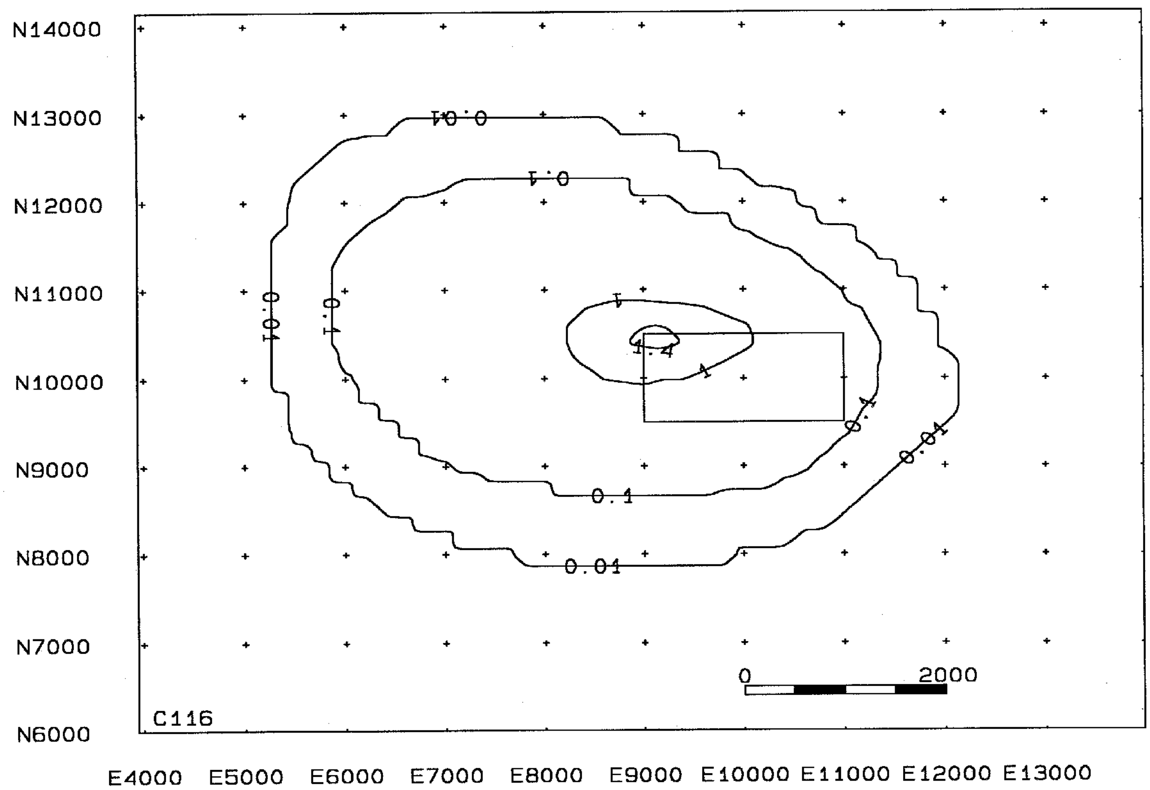


Figure E7. PV shelf in situ cap thickness contours from placing 0.1 mm sand in the spreading mode in 60 m of water.

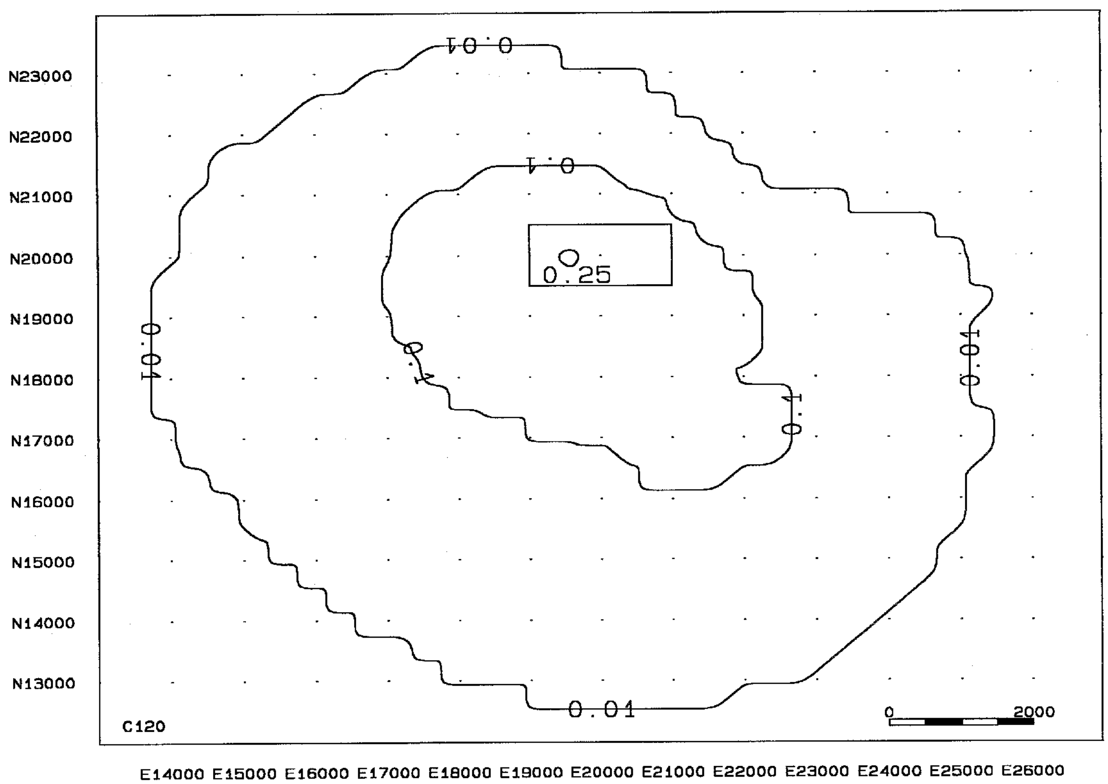


Figure E8. PV shelf in situ cap thickness contours from placing 0.04 mm silt in the spreading mode in 60 m of water.

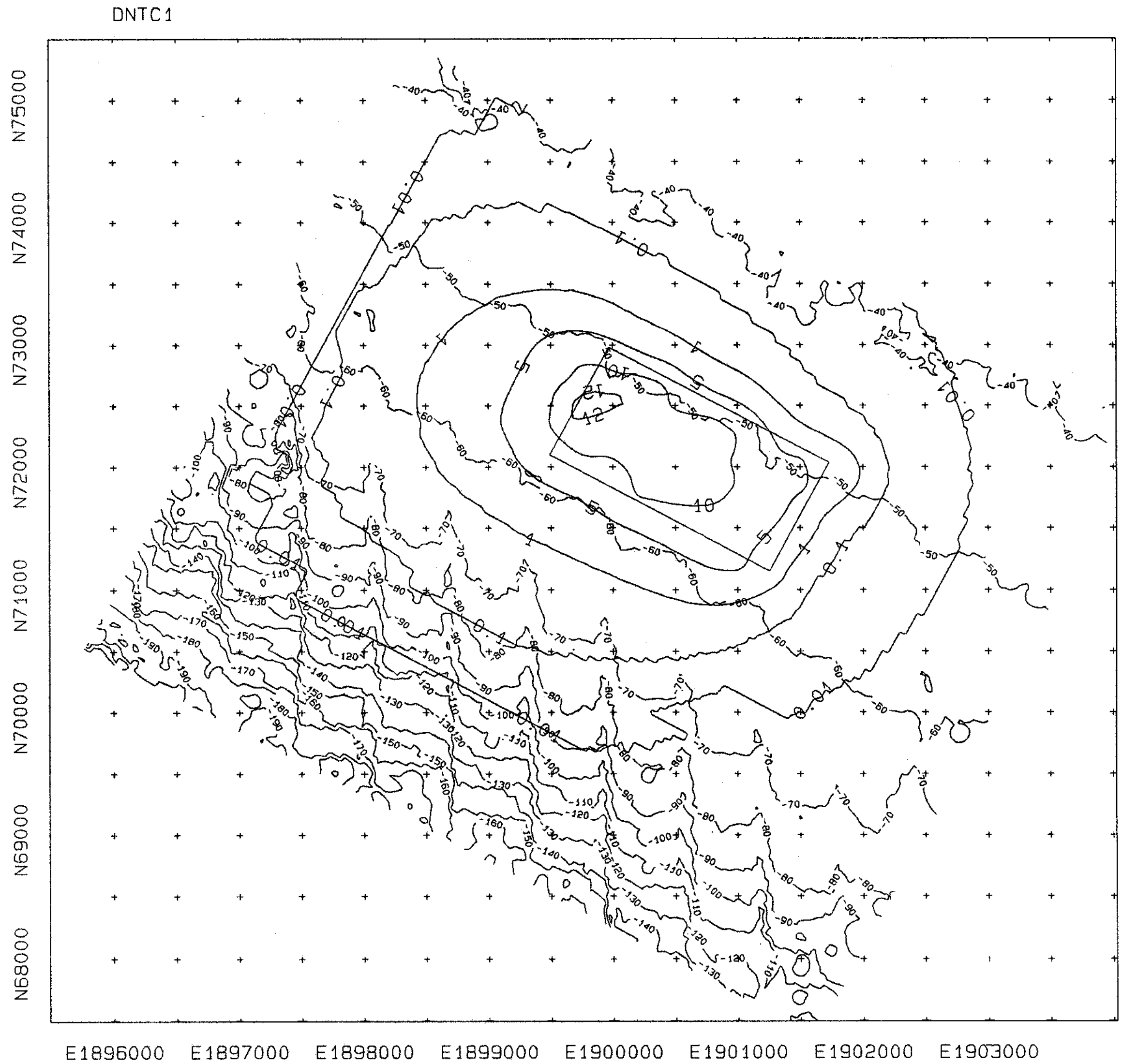


Figure E9. PV shelf in situ cap thickness contours from placing 81,000 cy of Queen's Gate sediments using conventional bottom dumping.

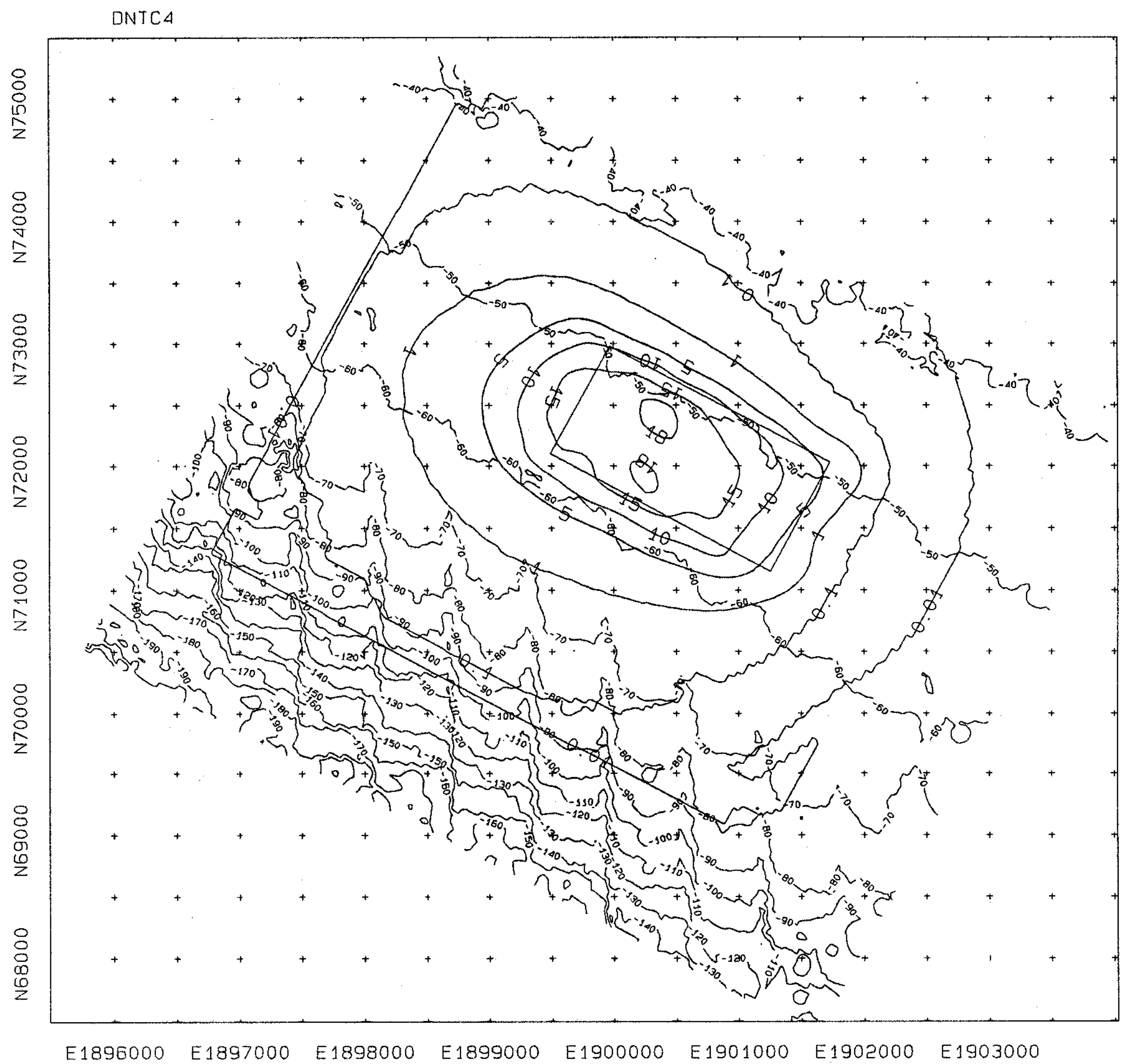


Figure E10. PV shelf in situ cap thickness contours from placing 119,000 cy of Queen's Gate sediments using conventional bottom dumping.

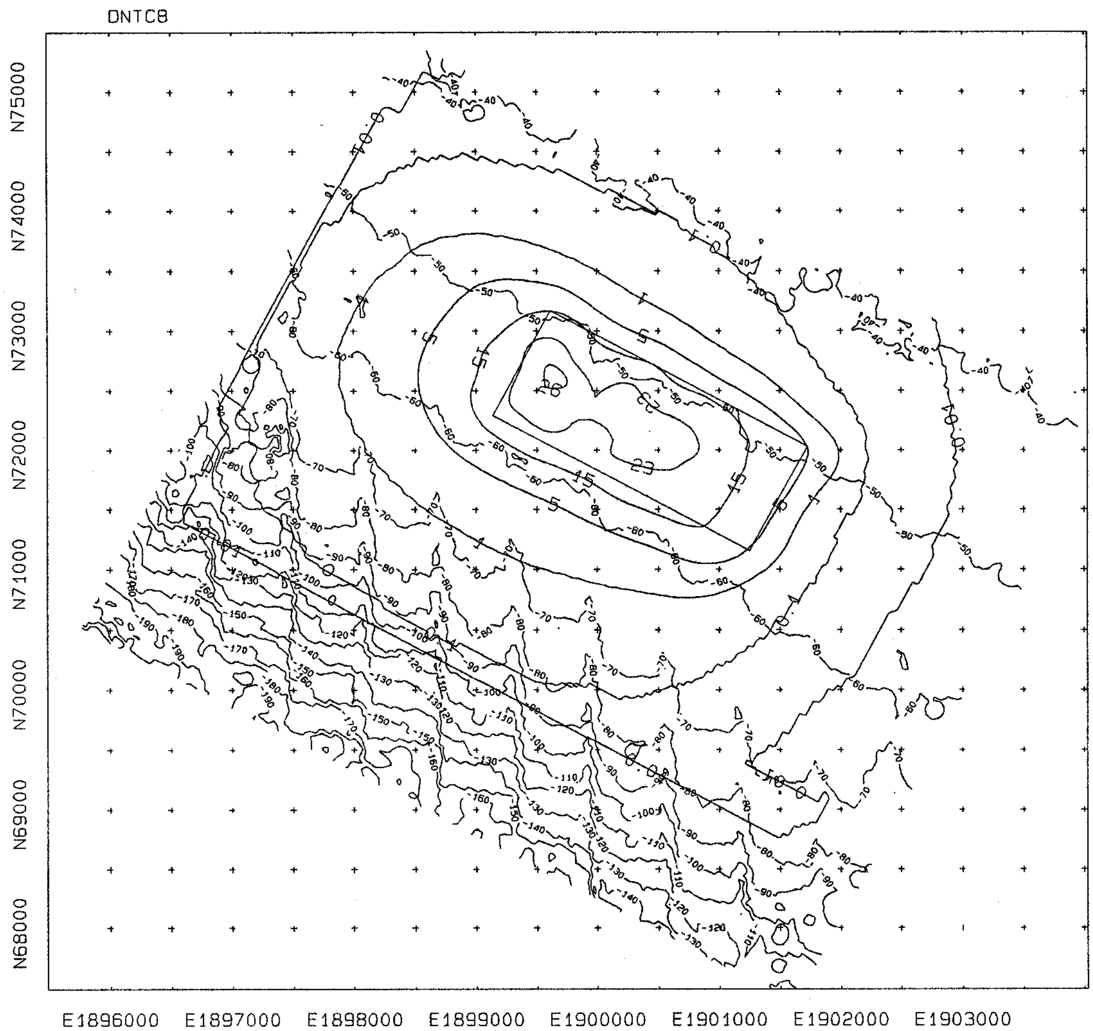


Figure E11. PV shelf in situ cap thickness contours from placing 184,000 cy of Queen's Gate sediments using conventional bottom dumping.

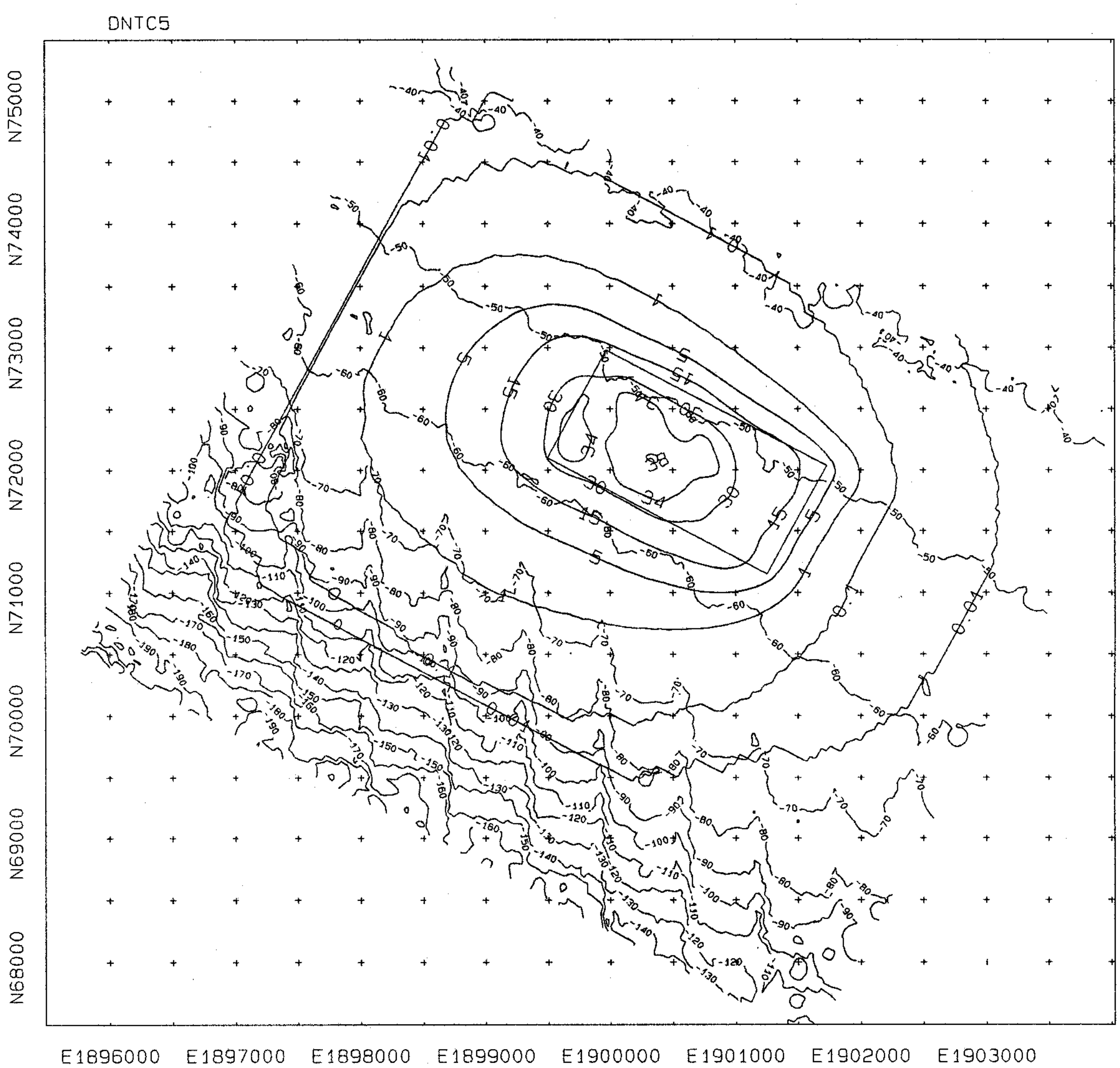


Figure E12. PV shelf in situ cap thickness contours from placing 237,000 cy of Queen's Gate sediments using conventional bottom dumping.

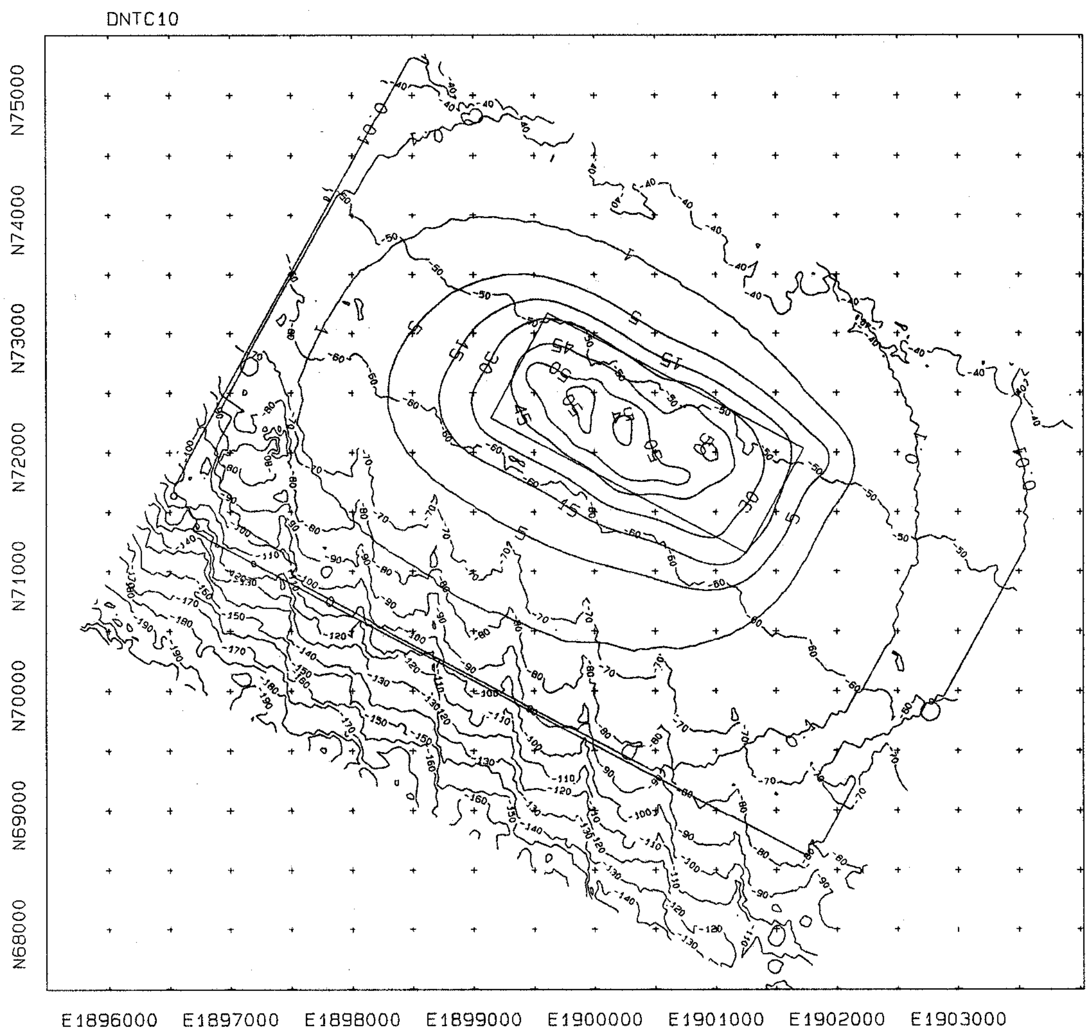


Figure E13. PV shelf in situ cap thickness contours from placing 367,000 cy of Queens Gate sediments using conventional bottom dumping.

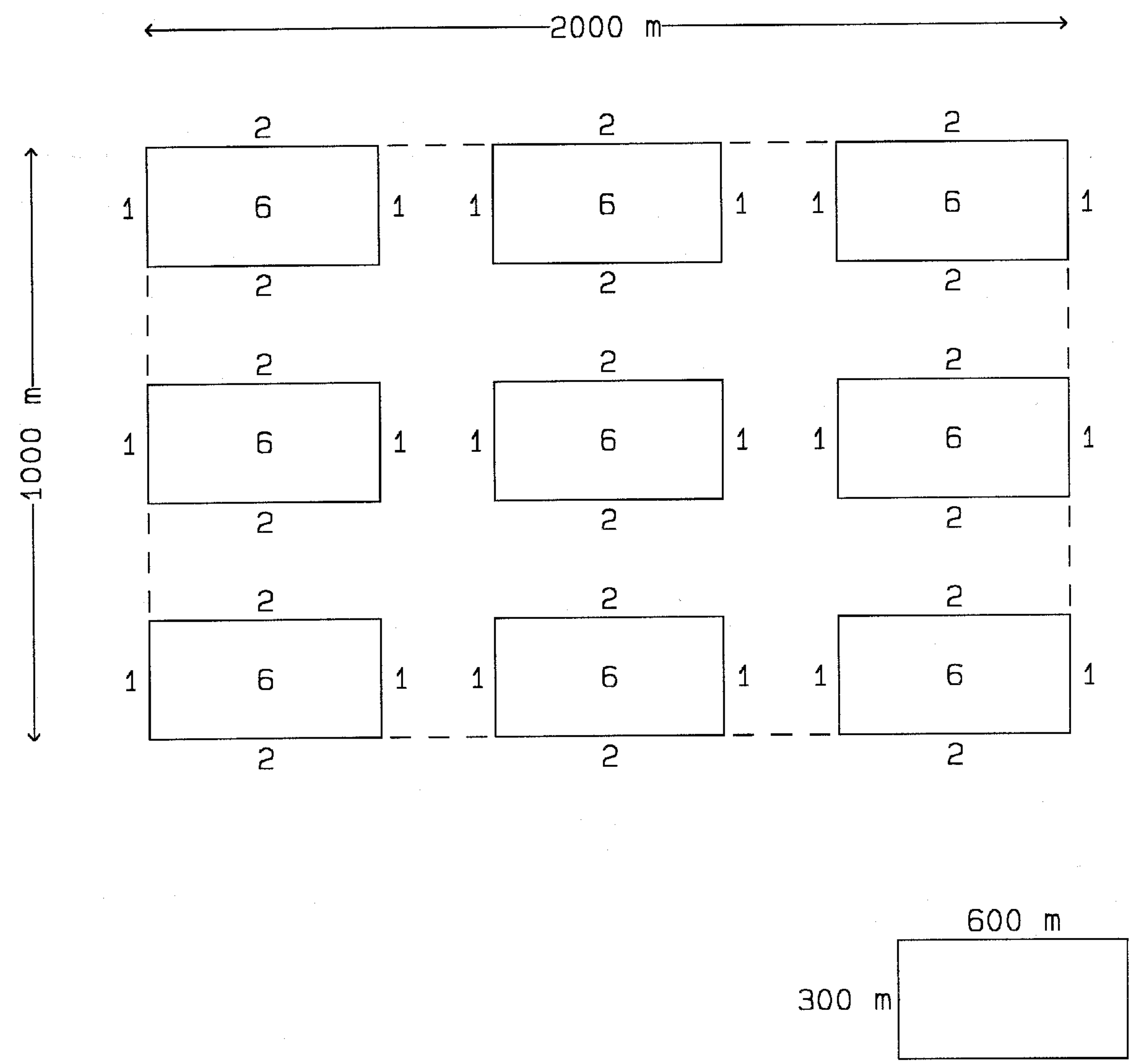
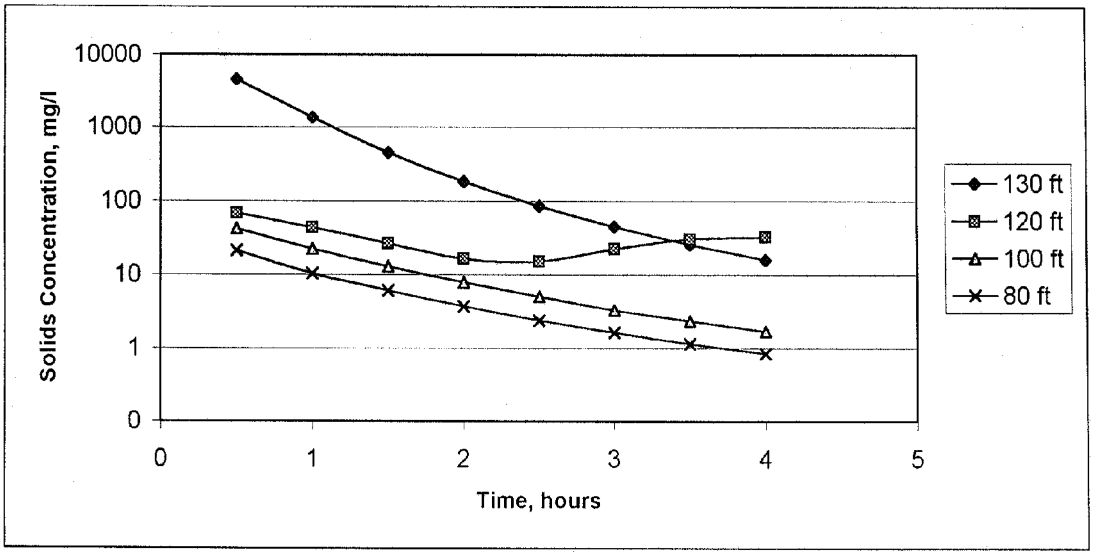


Figure E14. Illustration of distribution of cap material to adjacent placement areas.

Maximum Plume Suspended Solids

40 m Placement Depth, Hopper Discharge, Queens Gate



40 m Placement Depth, Hopper Spreading, Queens Gate

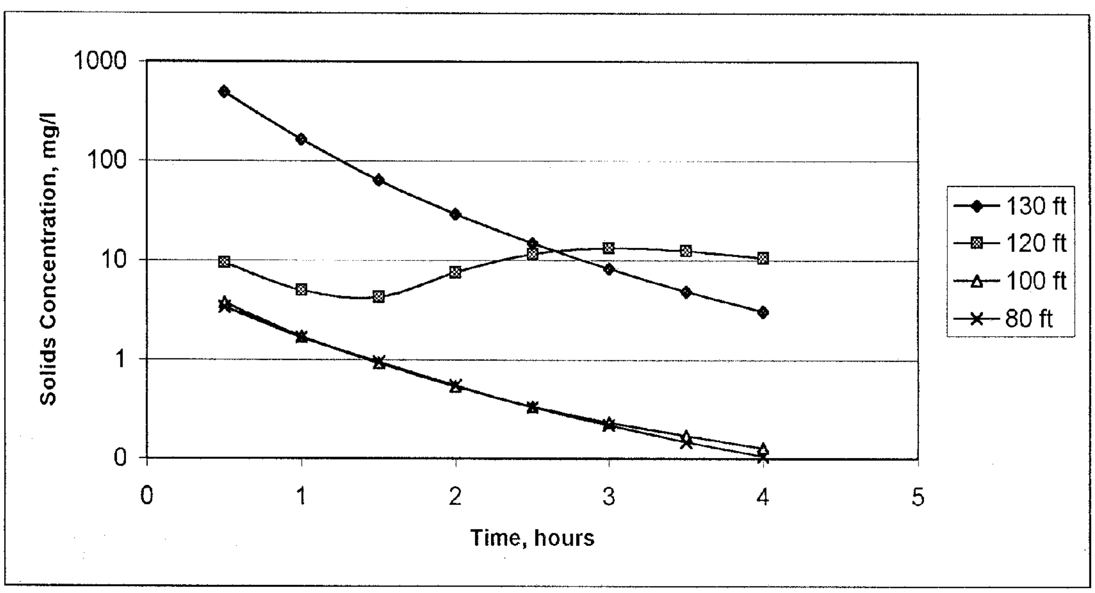
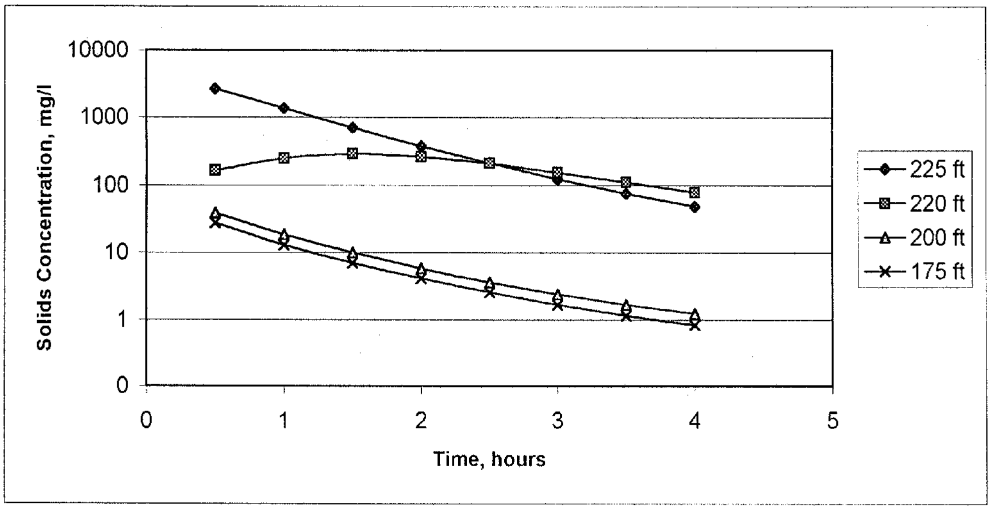


Figure E15. STFATE model results for Queen's Gate cap material plume suspended solids concentrations, 40 meter placement depth.

Maximum Plume Suspended Solids

70 m Placement Depth, Hopper Discharge, Queens Gate



70 m Placement Depth, Hopper Spreading, Queens Gate

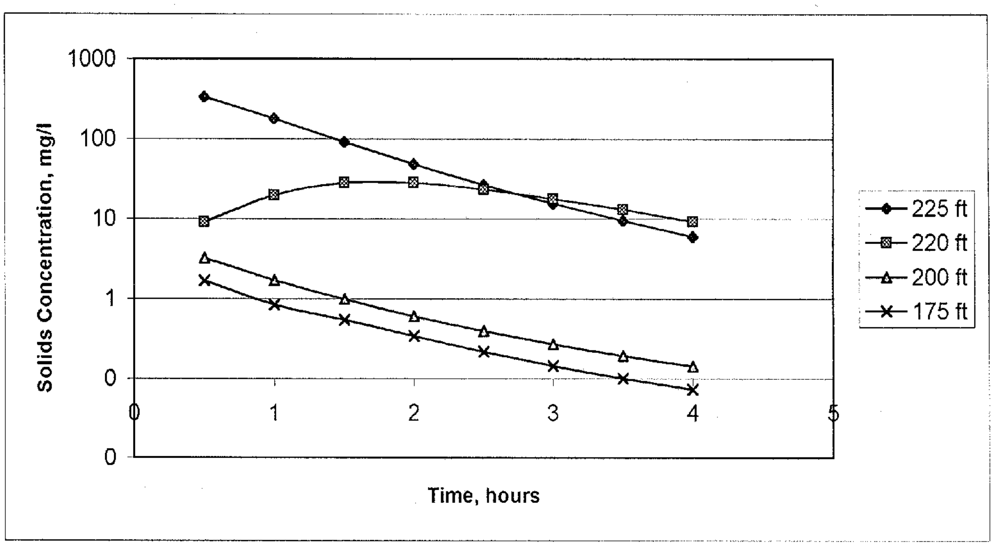


Figure E16. STFATE model results for Queen’s Gate cap material plume suspended solids concentrations, 70 meter placement depth.

Appendix F - Monitoring and Management

The U.S. Army Engineer Waterways Experiment Station (WES) is evaluating options for in situ capping for Palos Verdes (PV) shelf contaminated sediments. One necessary aspect of the study is an evaluation of monitoring and the development of a monitoring and management plan. A description of monitoring objectives and monitoring program phases and elements is presented in Chapter 5 of the main text of this report. This appendix provides the detailed description of specific monitoring elements and tiers, testable hypothesis for monitoring and proposed management actions to be implemented as a result of monitoring for each monitoring element.

Monitoring Schedule

All activities for both the construction monitoring and cap performance monitoring must be tailored to the anticipated construction schedule. Depending on the capping options, from 2 to 6 construction seasons would be necessary to complete construction if a single hopper dredge were used (see Chapter 4). Considering the schedule, all the monitoring activities and associated hypotheses and management decisions which are time dependent would necessarily be based on data acquired for individual cap placement cells or groups of cells completed during any specific construction season.

Cap Construction Monitoring

The evaluation of in situ capping options is based on results of previous capping experience, engineering investigations, and modeling. Using this information to evaluate design factors for a cap required making certain assumptions based on professional judgment. As a consequence, some monitoring to assure that the cap material is performing as expected would be necessary at the beginning of the project to allow modifications to the design if necessary. This will require a more detailed monitoring effort for the first few cells. Further, there would be an ongoing need for monitoring the cap construction to maximize the area effectively covered. Also, some testing of the cap materials would be needed to assure they meet specifications.

Specifically, there would be a need to (1) test the sediment being delivered to the site, (2) assure that the material spreads on the bottom as predicted (which is critical to cap design), (3) assure that the disposal pattern creates a uniform cap, and (4) assure that water quality impacts are not unacceptable.

Cap Material Quality

The elements of construction monitoring are typically defined in the quality assurance plan for the remedial construction, and may be conducted by the construction contractor, subcontractors and/or by independent agencies or contractors. The contract documents should define criteria or standards for all capping materials.

Samples of cap materials should be analyzed periodically to assure that they meet criteria specified in the contract, such as acceptable grain size distribution and maximum/minimum levels of total organic carbon (TOC). Cap materials should be analyzed using accepted laboratory methods (USACE 1970; ASTM 1992). This would include analysis of samples collected at the source or at the hopper dredge.

Data from core samples collected after placement (also a requirement under other monitoring elements) should also be used to assess cap material quality as placed. Analysis of granular materials following placement is especially important for in situ caps. Differential settling of granular materials during placement has the potential to cause segregation of materials by grain size. Fine-grained or less dense materials may be transported off-site during placement in waters with even small currents. Some cap placement methods can reduce these effects. However, the collection and analysis of samples of granular materials, post-placement, is the only way to determine if the cap, as constructed, meets the contract requirements.

Cap Thickness and Extent

Construction monitoring should include baseline, interim, and post cap material placement phases or increments to determine the cap thickness and extent. Baseline monitoring consists of determining the existing conditions in order to determine changes resulting from cap placement. Even though the in situ deposit has been characterized, a baseline monitoring effort would be needed to establish a baseline condition immediately prior to material placement, especially for the Sediment Profile Camera (SPC) surveys. Interim surveys would likely be necessary to determine where sufficient cap has been placed and where additional material should be placed. Finally, post cap material placement monitoring is used to confirm the final cap thickness and to serve as a baseline for future monitoring efforts.

The methods for cap placement should be specified to accomplish certain performance goals and criteria. These include maximum/minimum tolerance for cap placement (laterally), maximum/minimum tolerance for cap thickness, maximum tolerance for "mixing" of sediment and cap material, maximum levels of sediment resuspension, and maximum levels of sediment contaminants on the cap surface following construction.

Water depths in the areas defined for potential capping range from 40 to 70 meters, and the design cap thickness would be 15 to 45 cm. Further, the expected magnitude of consolidation as described in Chapter 3 would be on the order of a few cm. At these water depths, differential bathymetric surveys will not be useful in determining cap thickness as initially placed or changes in cap thickness due to consolidation. Appropriate techniques for monitoring cap placement for these site conditions include sub-bottom acoustic surveys, sediment core sampling, and sediment profiling camera images.

Acoustic subbottom profiling is based on the same principles as acoustic depth sounding and can be used to obtain images of the sediment layering along survey lines. Subbottom profiler signals penetrate the seafloor and can detect the thickness and relative composition of layers. In this way the thickness of the cap may be distinguished. If deployed by a submerged sled, the accuracy will not be reduced due to the water depths. The USGS used a chirp sonar device to obtain images of the EA sediment layer, and this same technology may be employed for this element of the monitoring program.

The Sediment Profiling Camera (SPC) is a monitoring tool which is recommended to detect thin layering within sediment profiles. The SPC is an instrument which is lowered to the bottom and is activated to obtain an image of sediment layering and benthic activity by penetrating to a depth of 15-20 cm. The SPC should be used to monitor the thickness of cap material and examine any mixing of cap material and contaminated sediments. The limiting depth of penetration of the SPC of 15-20 cm would allow easy and inexpensive monitoring of cap thickness during the capping process, and the images can be used to determine if the cap thickness is in excess of 20 cm. These data in conjunction with sub-bottom acoustic profiles and cores would provide assurance that the cap has been properly placed.

Sectioned cores (either vibracores or box cores) are the primary means of sampling the cap and can also be used to confirm the thickness of cap material. Samples from the cores can be analyzed for both physical properties, such as porosity and grain size, and the presence of sediment contaminants. In general, the cores should sample the full thickness of the cap and the underlying contaminated material. The maximum thickness of the contaminated layer is approximately 50 cm and the average is about 30 cm. For a 45 cm cap, the maximum total length of a core would therefore be one meter or less. The USGS successfully sampled the shelf sediments with a large box core, and this equipment is likely to be the optimum.

Sediment Resuspension

Contract criteria for limiting sediment resuspension during ISC placement may require monitoring. Such monitoring has been conducted at the Hamilton Harbor ISC and at the Wyckoff/Eagle Harbor Superfund site (Nelson,

Vanderheiden, and Schuldt 1994). Turbidity instruments can be used to locate and track any plumes due to cap material placement and EA sediment resuspension. Water samples are recommended for confirming compliance with specific requirements. The resuspension monitoring would likely be more intensive for the first few cells monitored, with a lesser intensity for subsequent cells if resuspension is found to be within the requirements.

Cap Performance Monitoring

Once the cap is in place there is a need to assure that the cap is not eroded, that contaminants are not being transported through the cap, that the biological community is recovering, and that the cap is not being disrupted by deep burrowers. Cap performance monitoring conducted at specified intervals over the long term is therefore required.

Cap erosion, contaminant transport, and biological recovery would be measured in a fairly direct manner. Cap impacts by deep burrowers would be better addressed by indirect measures as discussed in the next paragraphs.

Concerns about potential impacts by deep-burrowers on the cap could be assessed by both direct measurement of organism abundance or by measuring the effects of their activities. Of more significant importance is whether an effect is occurring, whereas abundance measurements may be of limited use in assessing actual impacts. For this reason, the monitoring approach should target measuring changes to the cap that would occur if deep burrowers were having an impact on the distribution of contaminants and not direct measurement of abundance. Approaches to assess abundance may be considered at a later date if they prove to be reliable and of sufficient use (e.g., use of laser line scan systems).

Deep burrowers would affect the cap either by transporting more contaminated sediment to the surface (this effect needs to be differentiated from normal deposition from surrounding off-cap contaminated areas) or homogenizing the cap with the underlying material. Monitoring would focus on measuring the stability of the chemical profile.

Monitoring approaches for these concerns should include sediment and pore water chemistry profiles from cores, sediment physical structure from cores, benthic community structure, and contaminant tissue concentrations of resident benthic species. These and other monitoring techniques discussed below can all be considered within the framework of a tiered monitoring plan and conducted on time intervals ranging from months to years.

Cap Erosion

To evaluate the performance of the ISC in physical isolation, a monitoring program must demonstrate that the cap is intact, covers the contaminated sediment deposit, prevents the physical loss of contaminants, and that benthos are not able to penetrate the cap. The elements of the monitoring program include measurements of sub-bottom acoustic profiling of the capped area, cap/component thickness and properties determined by SPC and cores, and benthos colonizing the cap.

Contaminant Transport

In order to evaluate the chemical isolation function of an in situ cap, the long-term migration of contaminants must be measured. Given the low predicted rates of flux, any unexpected large fluxes should be easy to detect and monitor for. Chemical analysis of sectioned cores is the most straightforward approach for evaluation of the long term isolation effectiveness of the cap.

Biological Recovery

Benthic organisms are usually sedentary and often are considered good indicators of the effects of physical and chemical alterations of the environment. Benthic sampling devices include trawls, drags, box corers, and grab samplers. Trawls and drags are qualitative samplers which collect samples at the bottom interface, and therefore are good for collecting epifauna and shallow infauna (top few centimeters). Quantitative samples are usually obtained with box corers and grab samplers. Generally these samplers collect material representing 0.02 to 0.5 m^2 of surface area and sediment depths of 5 to 100 cm. SPC images provide visual information on benthic organisms.

Monitoring efforts focused on fish should be carefully considered. Fish and many shellfish are mobile, and therefore data using these organisms is more difficult to relate to cause and effect. Sampling design using such mobile species needs to carefully consider effects of scale and migration dynamics.

Sampling of tissues of marine biota which colonize the mound also needs to be carefully considered. Typically the chemical analyses require about 15-30 gm (wet weight) of tissue per replicate. Unless the particular region has large bodied resident species that are easily collected, it may take a day or more of field collection per station to obtain the necessary sample requirement. Tissue sampling is also complicated by the natural variation of benthic populations in both space and time. In some years the target species may be very abundant, while in other years the species can be rare. These factors can result in very large monitoring costs or produce data which are of limited value.

A major complicating factor for this site is the fact that large areas on the slope will not be capped, and recontamination of the surface layer is possible. This should be taken into account in interpretation of tissue concentrations of organisms recolonizing the site.

Severe Event Response

After a severe storm, one with a 10 to 20 year return period, or a major earthquake, a modest monitoring program should be conducted to confirm the cap has not suffered any significant damage. Monitoring required after a severe storm would be limited to a number of cores, SPC stations and subbottom profiles.

Other Monitoring Methods

Several other monitoring tools can be considered in addition to the more conventional SPC, cores, and profiling techniques. Such tools may provide additional insight, especially into the effectiveness of the cap with respect to contaminant flux.

Small, semi-permeable bags filled with doubly distilled water have been used for monitoring the levels of nutrients and metals in sediment pore water. These devices, known as "peepers," have been adapted for use at an ISC site at Hamilton Harbor, Canada (Rosa and Azcue 1993; Azcue, Rosa, and Lawson 1996; Zeman and Patterson 1996).

A seepage meter device was considered for monitoring at an ISC site at Manistique Harbor, MI. Water seeping upward from the cap into the device would be channeled into a collection vessel which could be removed/replaced without disturbing the cap (Blasland, Bouck & Lee 1995). The U.S. Navy has also developed a contaminant flux chamber with similar potential application. Such monitoring devices could be considered to supplement the monitoring tools described above.

Testable Hypotheses and Tiers

Testable hypotheses should be established which are tied to critical threshold levels which, when exceeded, trigger a higher monitoring tier or implementation of a management action. Development of reasonable and testable hypotheses requires a prediction of the end result of the various processes which may occur at the site. A null hypothesis is developed (i.e., that there is no significant difference between predicted and observed conditions), and if the threshold is exceeded, the null hypothesis is rejected.

Tiers should be structured so that early warning of potential problems can be detected. Often physical monitoring may be the best tool in the lowest tier, but

biological or chemical tools may have appropriate roles in the lowest tier as well. The key is to get relatively rapid, inexpensive, and interpretable results.

Specific questions to be addressed by elements of the program and stated null hypotheses (Ho) **are typed in bold** in this appendix. Flowcharts are shown below for each element indicating the appropriate monitoring Tiers with thresholds and additional monitoring requirements or management actions should the threshold be exceeded.

Cap Construction Monitoring

Does the cap material meet specified quality standards?

H_o: Ninety (90%) percent of the samples analyzed from the delivered cap material meet the specified grain size distribution.

To assure that the sediment as transported to the site prior to placement meets the quality specifications, grain-size samples should be taken of 5% of the barge or hopper loads to determine grain-size. Selection of barges to be sampled would be done in consultation with the EPA program manager, but initially sampling should be frequent to allow for corrective measures, if necessary. Samples would be analyzed using either EPA or Corps of Engineers methods to determine the density, distribution and percent of sand, gravel, and cobble sized particles, as well as the percent silt and clay. Results would be compared to the specifications for the cap material. If any sample does not meet the specification, then sampling of each barge would be required (this would be beyond the 5% routine effort) until it can be established that 90% of the sediment does meet the specification (unless there is acceptance to relax the specification). See Figure F1.

Does the disposed cap sediment spread and mound as predicted?

H_o: Sediment point disposed at a specified depth and line and placement spacing will form a deposit with dimensions within ±20% of that predicted by modeling.

After disposal of the required number of barge loads for an initial cap placement cell, the contractor should conduct detailed sediment profile camera surveys and sub-bottom acoustic surveys to confirm model predictions.

Twenty-one (21) stations in a star shaped array should be occupied with three photographs taken at each station. Spacing between stations should be determined in consultation with the EPA project manager in accordance with the predicted spread of material. Cap thickness should be measured in each photograph.

The contractor should conduct a sub-bottom sediment profile survey over each disposal point. The survey would cover the entire cap placement area (unless predictions suggest otherwise) with lane spacing of 25 m. Data would be analyzed and mapped (mosaiced) to provide the areal distribution of cap thickness. This survey would be used to complement the information provided by the sediment profile camera survey. See Figure F2.

Does the planned disposal operation provide a cap with acceptable uniform thickness?

Does the planned disposal operation, once all disposal operations are complete, provide a cap with acceptable uniform thickness?

H_0: Sediment point disposed at the specified spacing will result in creation of a cap with a thickness greater than the design thickness over 95% of the area and no less than 75% of the design thickness over the remaining 5% of the area.

As the required number of hopper loads are placed over each cap placement cell, the contractor would conduct sub-bottom acoustic surveys to confirm capping point design spacing.

The contractor would conduct a sub-bottom sediment profile survey over the capped area to assure that a uniform cap is being created by the overlapping deposits. The survey would cover the capped area with lane spacing of 25 m. Data would be analyzed and mapped (mosaiced) to provide the areal distribution of cap thickness.

For areas capped at the 15 cm thickness, a SPC survey would be conducted over the defined grid. The contractor would also take (cores) from the each cell that penetrate through the cap. These cores would be split and the thickness of the cap measured. These data would be used to augment the sub-bottom profile data.

Following completion of all capping operations, the contractor should sub-bottom survey the entire cap to assure cap thickness and provide baseline conditions. See Figure F3 and F4.

Is resuspension of contaminants during capping unacceptable?

H_0 Water samples taken within the plume, within 3 meters of the bottom, do not exceed specified water quality criteria (to be determined).

To assure that unacceptable impacts to water quality are not occurring, the contractor should track the sediment plume for the initial cap placement cell operations and 2% of the total (unless the impacts are found to be extremely

minimal, then this sampling may be eliminated) using an acoustic doppler current profiler (ADCP). At one (1) hour after disposal, a pumped water sample would be taken from the center of the plume within 3 meters of the bottom (unless the plume centroid is higher in the water column). The sample would be taken and processed using EPA approved methods. The sample would be analyzed for dissolved contaminants, with the results reported within 24 hours.

If water quality violations occur, changes to the disposal operation may be necessary. This may involve slower disposal of cap sediment or greater overlap of cap deposits to minimize resuspension of ambient material. See Figure F5.

Cap Performance Monitoring

Is the cap recolonizing as expected (indicating lack of contaminant effects and that this desired remediation objective is met)?

H_0 One year after cap construction, 90% of the benthic stations are characterized by Stage II or Stage III communities.

The contractor should conduct a sediment profile camera survey over the capped area with three photographs taken at each station. Photographs will be analyzed for cap thickness and benthic recolonization parameters (successional status, RPD depth, OSI, etc.). The time period for the sampling refers to one year following the completion of the cap over a given area of the shelf. See Figure F6.

Is the cap isolating contaminants?

H_0 Samples taken 12 cm above the cap interface will show no significant increase in contaminant levels following cap creation.

The contractor should take gravity, piston, box, or vibracores of sufficient length to penetrate through the cap into the contaminated sediments. These cores would be split and visually described along their length by a marine geologist to assess layer integrity. Sediment chemistry samples would be taken at 4 cm increments both above and below the cap/contaminated interface. These samples would be taken using standard EPA collection and storage procedures for delivery to the analytical testing lab. Samples would be analyzed for sediment density, grain size, TOC, and contaminant concentrations.

This hypothesis applies only to the isolation cap alternative. Increases in contaminant levels at the sediment surface would not necessarily indicate a problem with cap performance, since this could result from transport of contaminants from adjacent uncapped areas. Increases below the depth of intensive bioturbation, but above the cap interface would indicate that the cap was not isolating the contaminants in the long term. See Figure F7.

Are deep burrowers re-exposing unacceptable volumes of contaminated sediment?

$H_0$1: The cap remains as a distinct geological feature of the seabed.

$H_0$2: Accumulation of contaminants at the sediment-water interface is not significantly different than predictions based on deposition from surrounding areas.

The contractor should take cores (gravity, piston, or vibracore, as appropriate) of sufficient length to penetrate into the contaminated layer. The cores would be split, visually described by a geological oceanographer to assess cap integrity, and sampled at the surface and in 4 cm increments. These samples would be delivered to the lab and analyzed for contaminants. Changes from the expected profile (considering deposition from off site) would be assessed.

If changes in chemical profiles are observed and no explanation besides burrowers is likely an assessment of burrower identification and density would be conducted in order to determine necessary corrective action. This may require use of spade box cores or laser line scan assessment of macrofaunal density. See Figure F8.

Is the cap eroding unacceptably?

H_0 Cap thickness exceeds the design thickness over 95% of the area and no less than 75% of the design thickness over the remaining 5% of the area.

The contractor should periodically conduct a sub-bottom sediment profile survey over the capped area to assure that a uniform cap is being maintained. The survey would cover the capped area with lane spacing of 25 m. Data would be analyzed and mapped (mosaiced) to provide the areal distribution of cap thickness.

The contractor would also take core from the surveyed area that penetrate through the cap. These cores would be split and the thickness of the cap measured. These data would be used to augment the sub-bottom profile data. The mapped cap thickness from this survey would be compared to earlier surveys of the site to assess cap erosion. See Figure F9.

Severe Event Monitoring

The contractor should be prepared to conduct surveys following either severe storm or seismic events. The major concern following these events is unacceptable impacts to cap thickness. Therefore the response to these events would follow the monitoring approach to cap erosion concerns just discussed.

The magnitude and characteristics of storm and seismic events that will trigger the severe event monitoring needs to be developed in coordination with the EPA program manager. However, for the first months or years after cap placement, these should be conservative triggers to assure that predictions about likely events that could affect the cap are reasonable.

Management Actions

As described in the tiered program above, the management actions deemed appropriate for this site include an increase in the monitoring effort to a higher tier, use of alternate cap materials or placement methods, placement of additional cap thickness, and cessation of capping activities.

References

American Society for Testing and Materials (ASTM). (1992). "Natural building stones; soil and rock; geotextiles," 1992 Book of ASTM Standards, Volume 04.08, American Society for Testing and Materials, Philadelphia, PA.

Azcue, J. M., Rosa, F., and Lawson, G. (1996). "An improved dialysis sampler for the In Situ collection of larger volumes of sediment pore waters," Environmental Technology, Vol 17, pp 95-100.

Blasland, Bouck, and Lee, Inc. (1995). "95% Design, Manistique River and Harbor," Prepared by Blasland, Bouck, and Lee, Inc. for Manistique papers Inc. and Edison Sault Electric Company, Manistique, MI.

Nelson, E.E., Vandeheiden A.L., and Schuldt, D.A. (1994). "Eagle Harbor Superfund Project," Proceedings of Dredging '94, American Society of Civil Engineers, NY, pp 1122-1131.

Rosa, F., and Azcue, J.M. (1993). "Peeper Methodology - A detailed procedure from field experience," NWRI Contribution No. 93-3, National Water Research Institute, Burlington, Ontario.

US Army Corps of Engineers (USACE). (1970). "Laboratory soils testing," Engineer Manual 110-2-1906, Washington, DC.

Zeman, A.J. and Patterson, T.S. (1996). "Results of the In Situ Capping demonstration project in Hamilton Harbor, Lake Ontario," NWRI Contribution No. 96-75, National Water Research Institute, Burlington, Ontario.

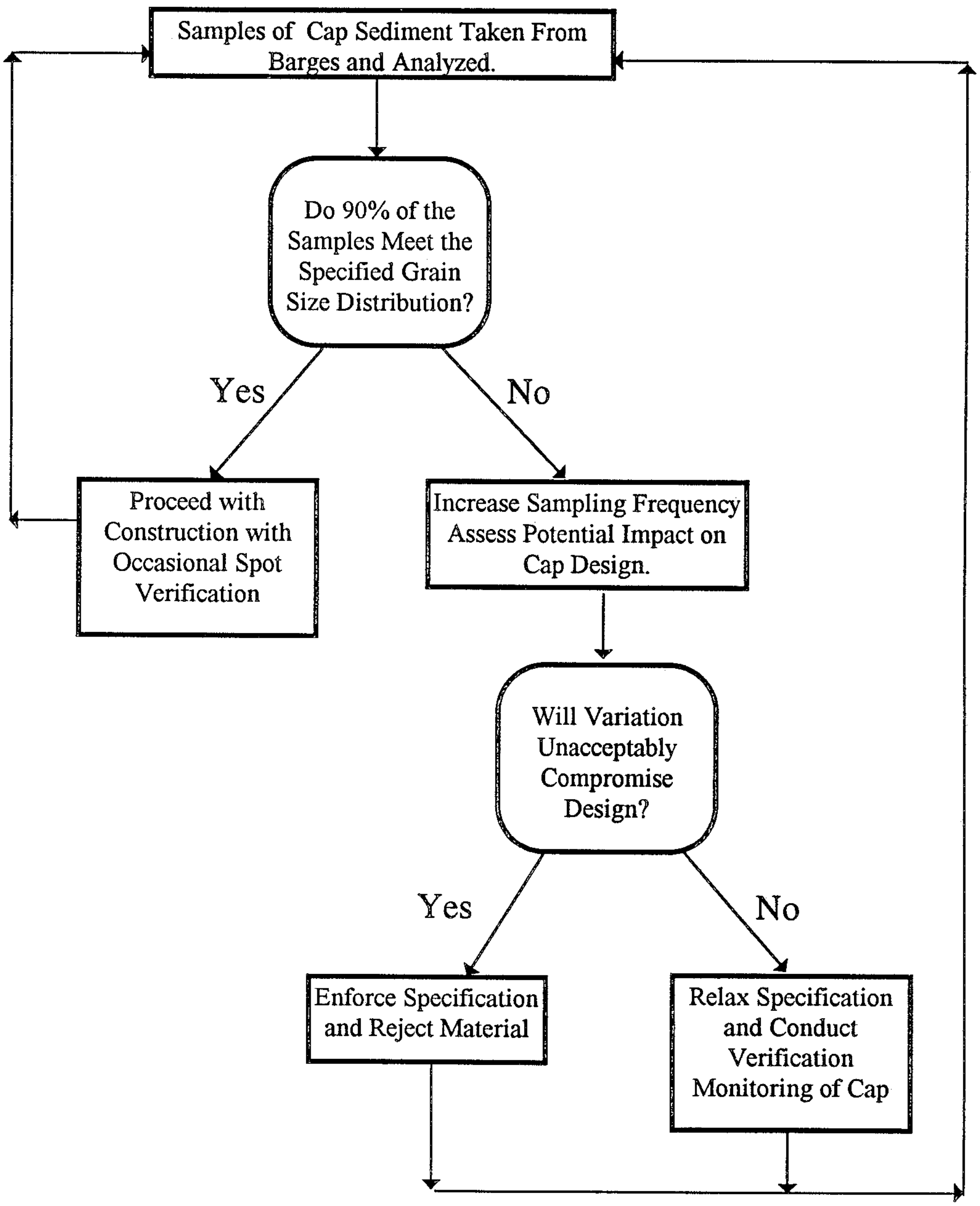

Samples of Cap Sediment Taken From Barges and Analyzed.
Do 90% of the Samples Meet the Specified Grain Size Distribution?
Yes
No
Proceed with Construction with Occasional Spot Verification
Increase Sampling Frequency Assess Potential Impact on Cap Design.
Will Variation Unacceptably Compromise Design?
Yes
No
Enforce Specification and Reject Material
Relax Specification and Conduct Verification Monitoring of Cap

Figure F1.

Disposal Depth (m)	Disposal Diameter (m)	Central Deposit (>5 cm) Diameter (m)	Height at Peak (cm)
30			
50			
70			
100			
150			

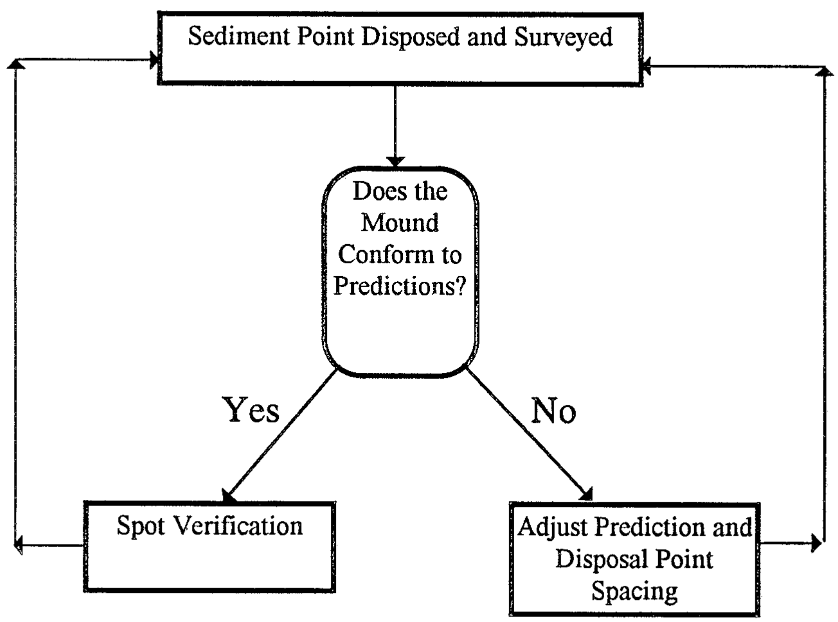


Figure F2.

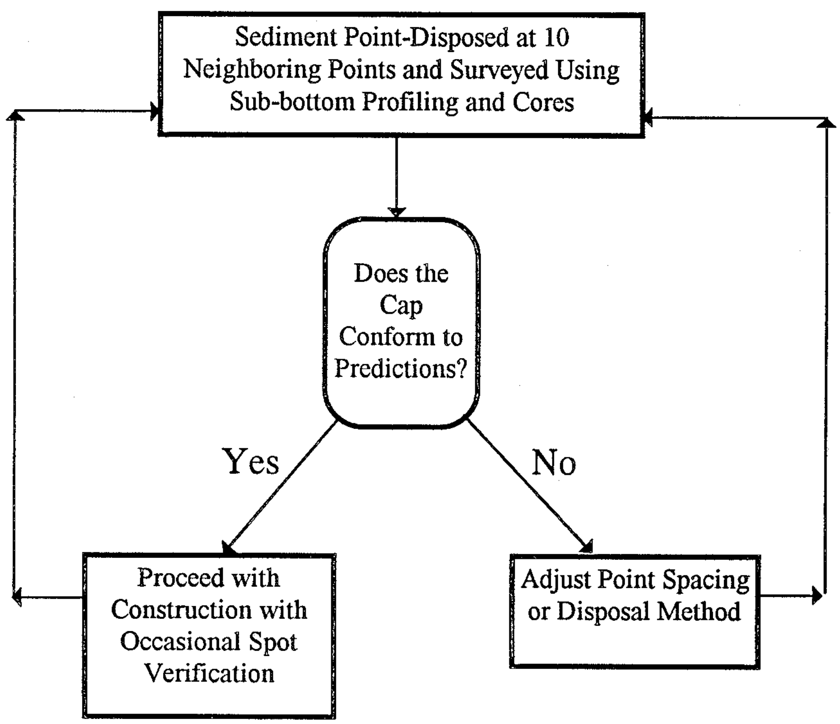
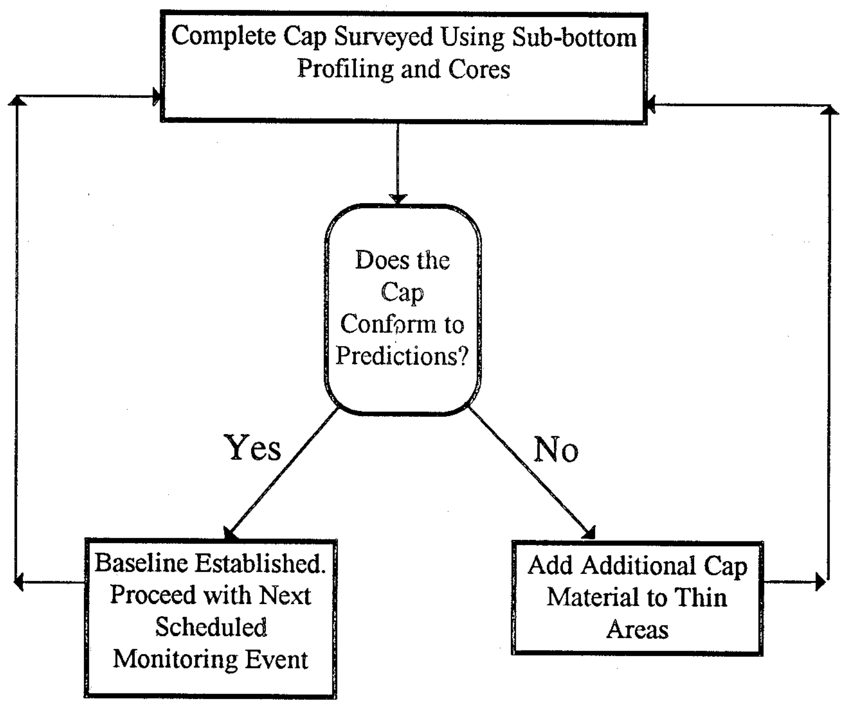

Sediment Point-Disposed at 10 Neighboring Points and Surveyed Using Sub-bottom Profiling and Cores
Does the Cap Conform to Predictions?
Yes
No
Proceed with Construction with Occasional Spot Verification
Adjust Point Spacing or Disposal Method

Figure F3.



Complete Cap Surveyed Using Sub-bottom Profiling and Cores
Does the Cap Conform to Predictions?
Yes
No
Baseline Established. Proceed with Next Scheduled Monitoring Event
Add Additional Cap Material to Thin Areas

Figure F4.

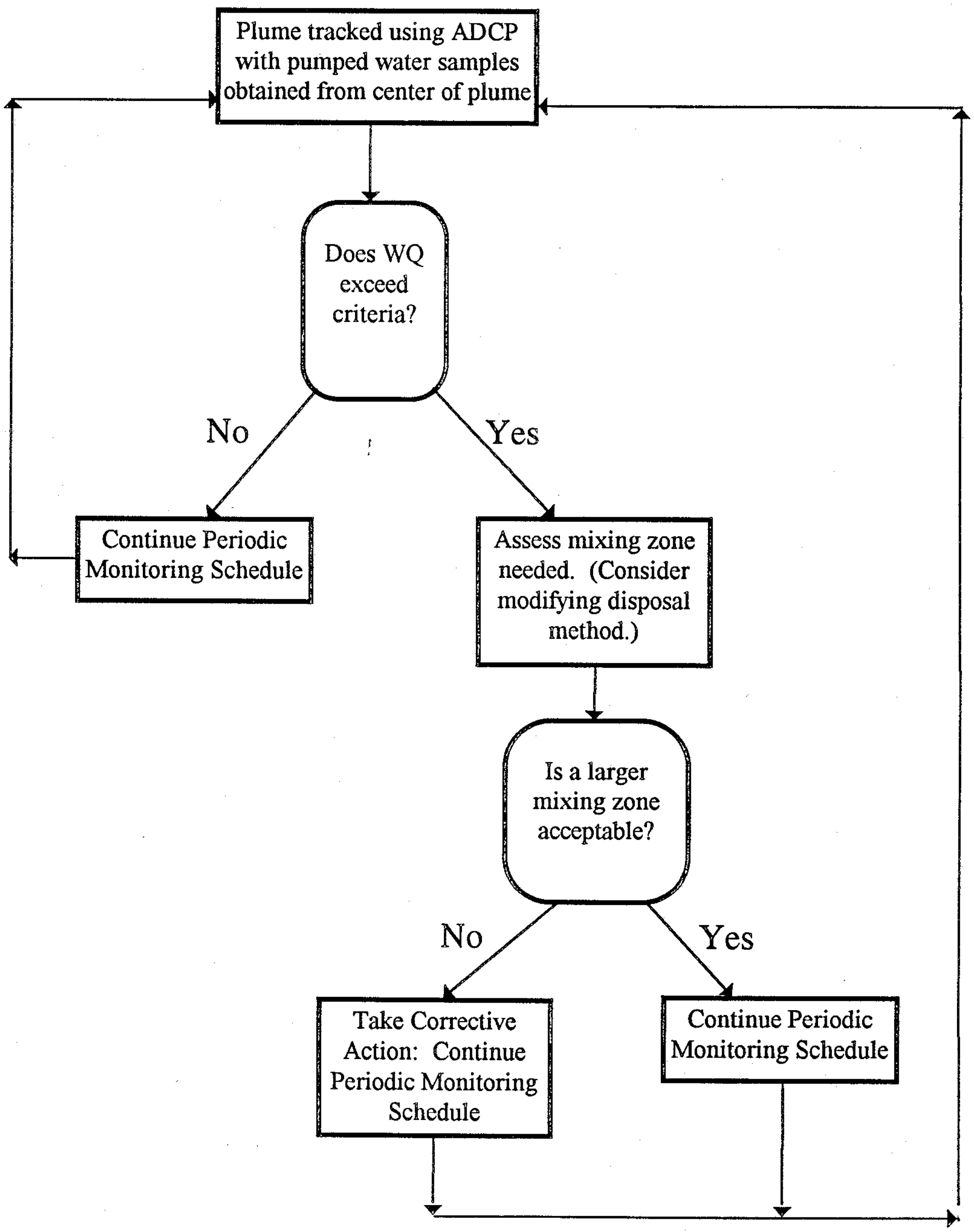

Plume tracked using ADCP with pumped water samples obtained from center of plume
Does WQ exceed criteria?
No
Yes
Continue Periodic Monitoring Schedule
Assess mixing zone needed. (Consider modifying disposal method.)
Is a larger mixing zone acceptable?
No
Yes
Take Corrective Action: Continue Periodic Monitoring Schedule
Continue Periodic Monitoring Schedule

Figure F5.

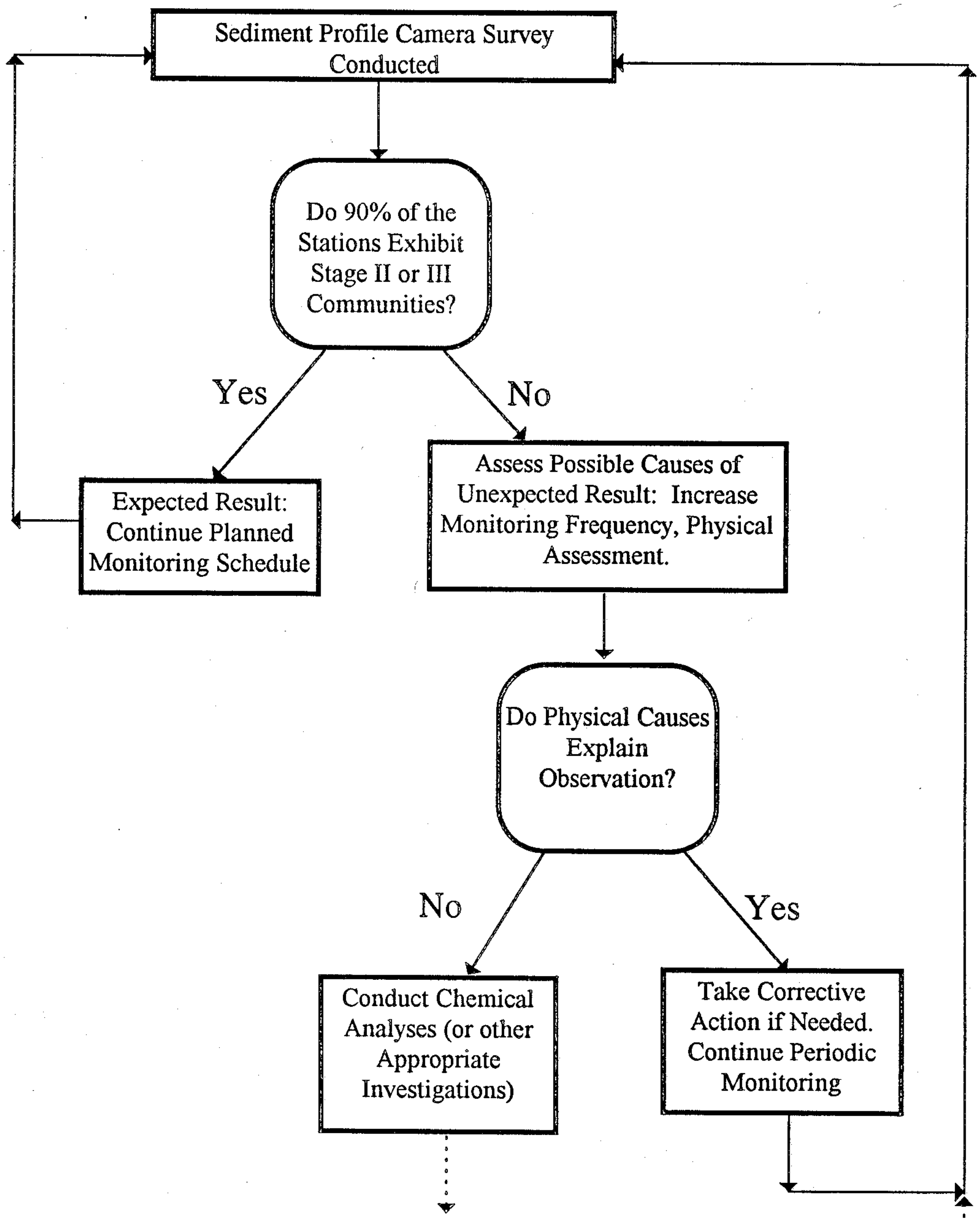

Sediment Profile Camera Survey Conducted
Do 90% of the Stations Exhibit Stage II or III Communities?
Yes
No
Expected Result: Continue Planned Monitoring Schedule
Assess Possible Causes of Unexpected Result: Increase Monitoring Frequency, Physical Assessment.
Do Physical Causes Explain Observation?
No
Yes
Conduct Chemical Analyses (or other Appropriate Investigations)
Take Corrective Action if Needed. Continue Periodic Monitoring

Figure F6.

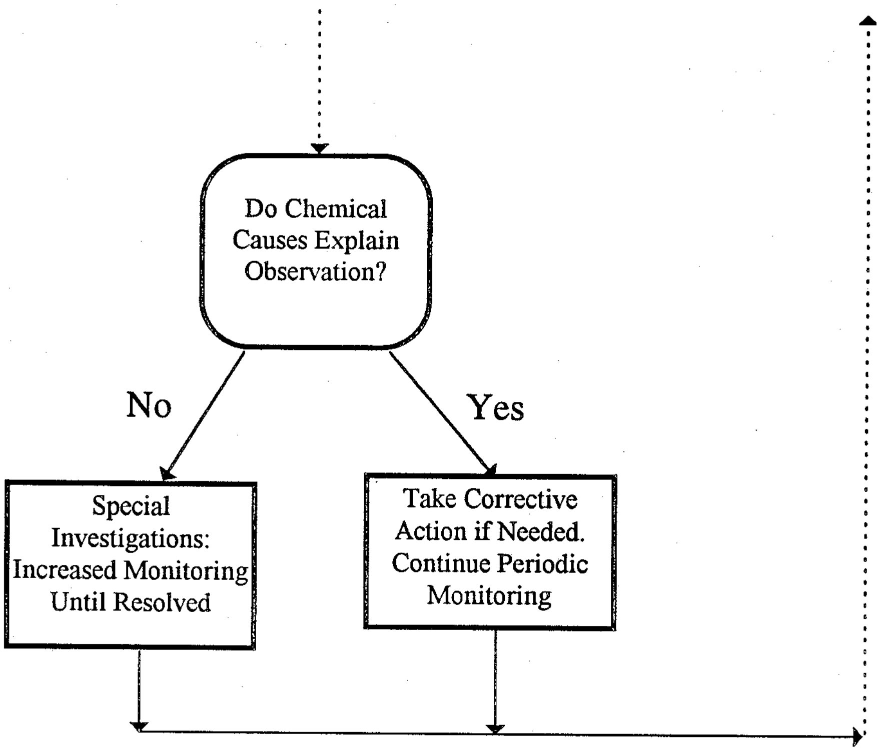


Figure F6 (concluded)

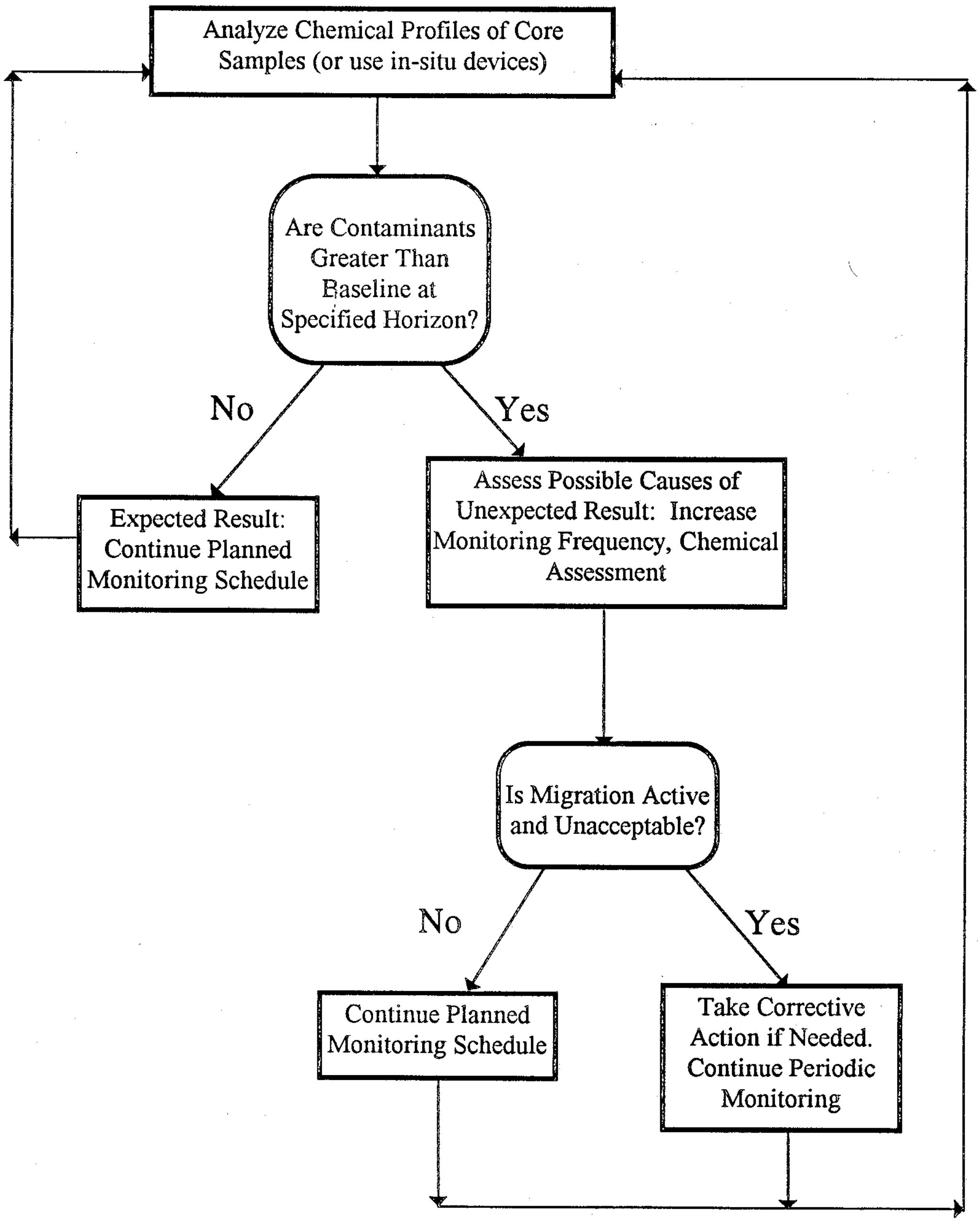

Analyze Chemical Profiles of Core Samples (or use in-situ devices)
Are Contaminants Greater Than Baseline at Specified Horizon?
No
Yes
Expected Result: Continue Planned Monitoring Schedule
Assess Possible Causes of Unexpected Result: Increase Monitoring Frequency, Chemical Assessment
Is Migration Active and Unacceptable?
No
Yes
Continue Planned Monitoring Schedule
Take Corrective Action if Needed. Continue Periodic Monitoring

Figure F7.

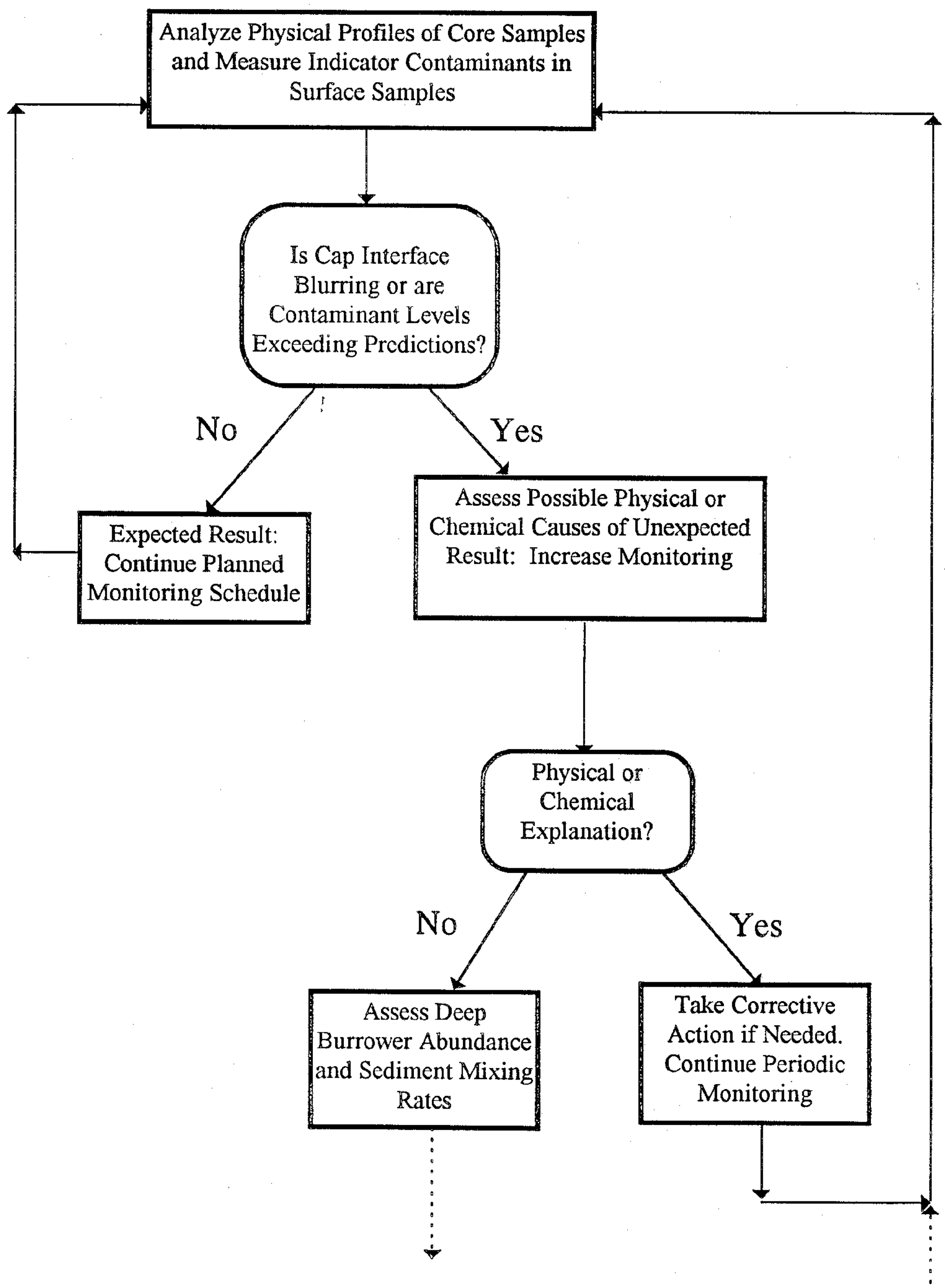

Analyze Physical Profiles of Core Samples and Measure Indicator Contaminants in Surface Samples
Is Cap Interface Blurring or are Contaminant Levels Exceeding Predictions?
No
Yes
Expected Result: Continue Planned Monitoring Schedule
Assess Possible Physical or Chemical Causes of Unexpected Result: Increase Monitoring
Physical or Chemical Explanation?
No
Yes
Assess Deep Burrower Abundance and Sediment Mixing Rates
Take Corrective Action if Needed. Continue Periodic Monitoring

Figure F8.

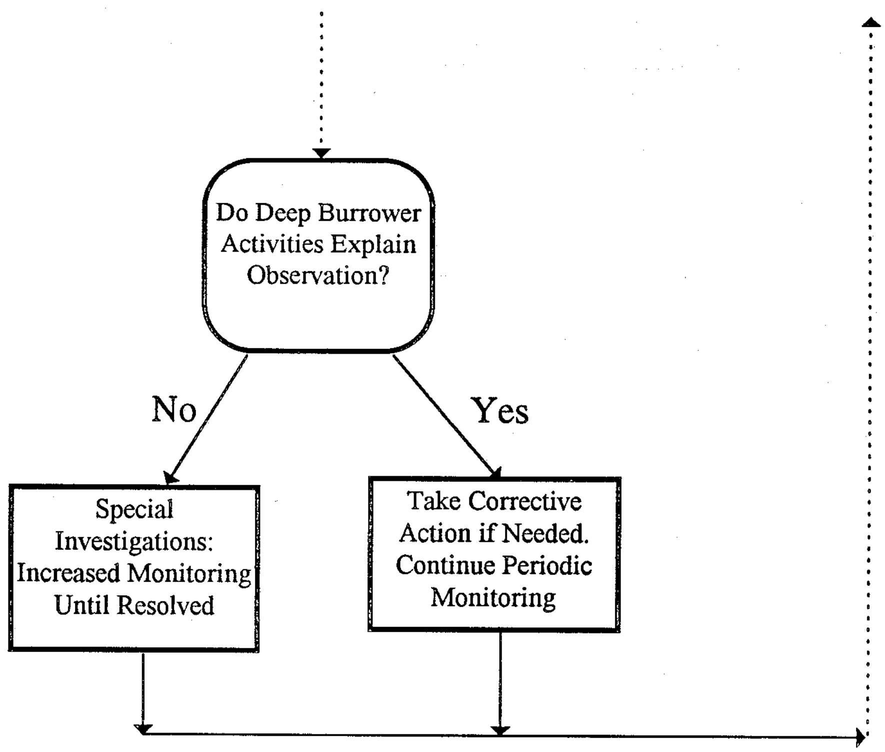
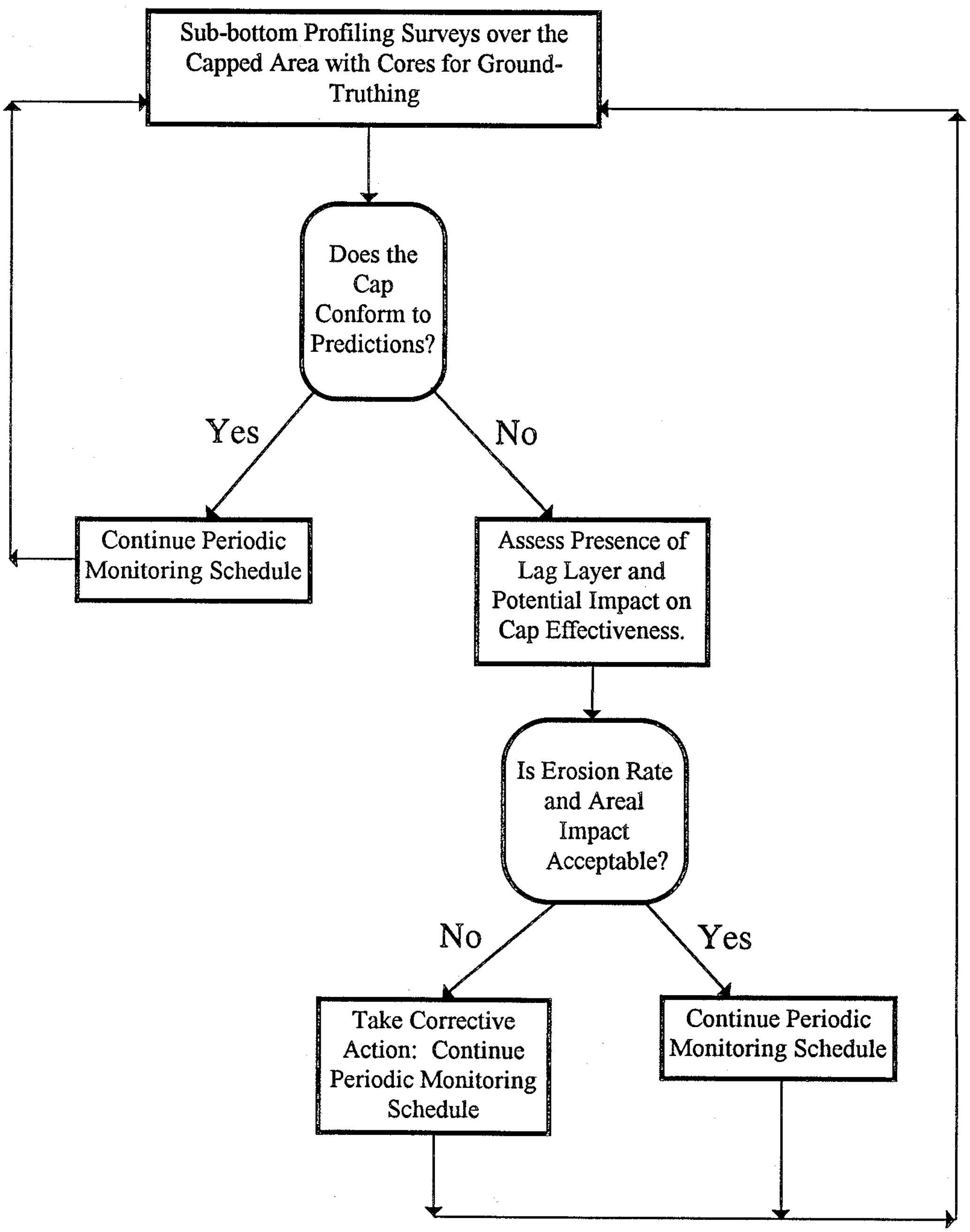


Figure F8 (concluded).



Sub-bottom Profiling Surveys over the Capped Area with Cores for Ground-Truthing
Does the Cap Conform to Predictions?
Yes
No
Continue Periodic Monitoring Schedule
Assess Presence of Lag Layer and Potential Impact on Cap Effectiveness.
Is Erosion Rate and Areal Impact Acceptable?
No
Yes
Take Corrective Action: Continue Periodic Monitoring Schedule
Continue Periodic Monitoring Schedule

Figure F9.

Appendix G - Cost Estimates

The U.S. Army Engineer Waterways Experiment Station (WES) is currently evaluating options for in situ capping for Palos Verdes (PV) shelf contaminated sediments. This appendix describes one aspect of the study, cost estimates for cap placement.

USEPA has designated an area offshore of White Point, San Pedro, California on the Palos Verdes Shelf as a superfund site for possible remediation. In situ capping of the shelf's contaminated bottom sediments is one of several alternatives currently under review by USEPA to remediate the site. Preliminary cost estimates of an in situ aquatic capping project at White Point were developed by the U.S. Army Corps of Engineers, Los Angeles District to assist in assessing the feasibility of this alternative.

Cost estimates were generated based upon the cost differential to transport the material to the White Point offshore site, from four (4) areas along the southern California coast, versus transporting the sediments to traditional aquatic disposal sites. The traditional aquatic disposal sites were identified as the designated ocean dumping sites LA-2 and LA-3, and in-bay disposal sites either within the waters of the Port of Los Angeles or the Port of Long Beach.

The preliminary estimates were calculated following discussions with local dredge contractors regarding expected costs to utilize various dredge and disposal platforms to place the dredged material at the project site. The equipment include hopper dredges, clamshell dredges (disposal with tugs & scows), and hydraulic pipeline dredges. The unit costs do not include the cost for mobilization and demobilization. Recently, mobilization and demobilization costs within the Los Angeles Basin have typically ranged around $500,000 for hopper dredges (although mob/demob costs for larger capacity hopper dredges may range up to $1,000,000), and $600,000 to $1,000,000 for hydraulic pipeline and clamshell (tug & scow) dredges. It is approximated that actual dredging costs (excluding transportation and disposal) for a clamshell dredge and a hydraulic pipeline dredge are $3.00/cy and $2.50/cy, respectively.

Four (4) southern California sites were identified as potential dredged or capping material sources. These sites include the Port of Los Angeles, Port of Long Beach, Upper Newport Bay (Orange County), and Portuguese Bend (Rancho Palos Verdes). Tables G1 through G4 contain unit cost matrices for the cost differential to transport and dispose dredged sediments. The differentials compare the cost to transport sediments from the four (4) dredged (capping) material source locations to the traditional in-water disposal sites, versus the cost to transport and dispose the sediments at the White Point (Palos Verdes Shelf) superfund site. These comparisons are provide in Tables G1 through G4.

The following assumptions were made to compute the preliminary cost estimates:

A. On station time for hopper dredge disposal operations at the capping site (White Point) is 0.50 hrs vs. an on station time at LA-2 and LA-3 of 0.25 hrs;

B. On station time for tug & scow disposal operations at the capping site (White Point) is 1.50 hrs vs. an on station time at LA-2 and LA-3 of 1.0 hrs and at the in-bay sites of 0.25 hrs;

C. The cost to dispose dredged material at an in-bay site utilizing a hydraulic pipeline is negligible;

D. Transportation of sediments excavated from a hydraulic dredge to the capping site would be accomplished by a tug & scow operation;

E. Cost of the Portuguese Bend material would include, not only the transportation and disposal costs, but also the excavation (or dredging) of sediments from a diked berm (reference 1 (b)) prior to transportation. These sediments would over a five (5) year period of time slough down into the bermed area from the Portuguese Bend hillsides, in accordance with the Rancho Palos Verdes Feasibility Study F-3 Technical, dated June 1997. Excavation of the sediments would take place once the bermed site reaches capacity;

F. Tug & scow packages would include large scows (2500 cy capacity) with large tugs to haul long distances and small scows (1500 cy capacity) with small tugs to haul short distances;

G. The LA-2 ocean disposal site was not a viable disposal site for sediments originating from Portuguese Bend;

H. The LA-3 ocean disposal site was not a viable disposal site for sediments originating from the Port of Los Angeles, Port of Long Beach, and Portuguese Bend;

I. In-bay disposal was a viable disposal option for dredged sediments originating from the Port of Los Angeles and the Port of Long Beach;

J. Sediments generated from Upper Newport Bay will be placed at the LA-3 site.[1]

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[1] LA-3 has been designated as a temporary site for the ocean disposal of dredged sediments. The temporary designation is valid through January 1, 2000. Sediments generated from Upper Newport Bay are proposed to be placed at the LA-3 ocean disposal site. If LA-3 closes after January 1, 2000, then LA-2 will most likely become the primary disposal site of choice for the Upper Newport Bay dredged sediments. However, transportation of the dredged sediments to LA-2 may be cost prohibitive to the local entities, which could result in an indefinite suspension of dredging activities within Upper Newport Bay. These assumptions were not reflected in the estimates.

K. Dredged material for tug & scow operations are slurried prior to release at the Palos Verdes Shelf disposal site.

L. Size of the hopper dredge is 3600 cy, however, the In-Hopper sediment volume is actually 1800 cy.

Dredged material volumes of less than 1,000,000 cy from the Port of Long Beach and the Port of Los Angeles were included as part of this cost analysis. Results are provided in Table G5. Volumes less than 1,000,000 cy would most likely be generated from maintenance dredging projects. Dredged material volumes from maintenance dredging projects within the two Ports normally do not exceed 50,000 cy on an annual basis.

Preliminary cost estimates to dredge material from an Offshore Borrow Area (AIII) located immediately south of the San Pedro Breakwater (Port of Los Angeles) and the West Anchorage area located at the Port of Long Beach were also included as part of this estimating effort. Results of the dredge and disposal estimates for the offshore borrow area (AIII) and the West Anchorage area are shown in Table G6 and Table G7, respectively. Assumptions regarding the estimates are included in Table G8.

Total Engineering & Design cost to prepare plans and specifications and environmental documentation for removal of sediments from the offshore borrow area or the West Anchorage area is approximated at $260,000. This estimate includes work to be performed by engineering (coastal and geotechnical), environmental, surveying, contracting, and cost estimating teams. The estimate also includes obtaining sediment samples from the dredge (borrow area) site, and performing testing and analysis of the samples.

Contingencies are not provide for the given cost estimates. Typically the Los Angeles District adds a 50% contingency to cost estimates developed under reconnaissance level analysis and 25% contingency to cost estimates developed under feasibility level analysis. Since these estimates are considered to be reconnaissance level cost estimates, it is recommended that a 50% contingency be added to all provided cost estimates.

A detailed breakdown of the transportation and disposal cost estimates are provided in Tables G9 through G50.

Table G1
Disposal Unit Cost Comparisons for Dredged Sediments Originating from the Port of Los Angeles. Values are given in dollars per cubic yard (does not include mob/demob costs)

EQUIPMENT	PV SHELF ($/CY)	LA-2 ($/CY)	LA-3 ($/CY)	IN-BAY ($/CY)	PV SHELF VS. LA-2 ($/CY)	PV SHELF VS. LA-3 ($/CY)	PV SHELF VS. IN-BAY ($/CY)
Hopper Dredge[1]	3.85	4.01	n/a	2.48	-0.16[4]	n/a	1.37
Tug & Scow[2]	4.50	4.33	n/a	3.45	0.17	n/a	1.05
Hydraulic Pipeline[3]	4.00	n/a	n/a	2.50	n/a	n/a	1.50

(1) Estimates are based on the unit costs to dredge, transport, and dispose the dredged material.
(2) Estimates are based on the unit cost to dredge ($3.00/cy), transport and dispose (slurry) the dredged material.
(3) Estimated cost to hydraulically transport and dispose the dredged material to an "in-harbor" disposal site was considered negligible. The cost differential was compute based on the unit cost to dredge ($2.50/cy), transport and dispose dredged material at the Palos Verdes Shelf via a "tug & scow" (slurry) operation versus the negligible cost for "in-harbor" disposal utilizing a hydraulic discharge pipeline.
(4) Negative cost differential values reflect that it is more cost effective to transport and dispose dredged sediments at the Palos Verdes Shelf versus the traditional disposal site.

Table G2
Disposal Unit Cost Comparisons for Dredged Sediments Originating from the Port of Long Beach. Values are given in dollars per cubic yard (does not include mob/demob costs)

EQUIPMENT	PV SHELF ($/CY)	LA-2 ($/CY)	LA-3 ($/CY)	IN-BAY ($/CY)	PV SHELF VS. LA-2 ($/CY)	PV SHELF VS. LA-3 ($/CY)	PV SHELF VS. IN-BAY ($/CY)
Hopper Dredge[1]	4.69	4.70	n/a	2.90	-0.01[4]	n/a	1.79
Tug & Scow[2]	4.96	4.86	n/a	3.74	0.10	n/a	1.22
Hydraulic Pipeline[3]	4.46	n/a	n/a	2.50	n/a	n/a	1.96

(1) Estimates are based on the unit costs to dredge, transport, and dispose the dredged material.
(2) Estimates are based on the unit cost to dredge ($3.00/cy), transport and dispose (slurry) the dredged material.
(3) Estimated cost to hydraulically transport and dispose the dredged material to an "in-harbor" disposal site was considered negligible. The cost differential was compute based on the unit cost to dredge ($2.50/cy), transport and dispose dredged material at the Palos Verdes Shelf via a "tug & scow" (slurry) operation versus the negligible cost for "in-harbor" disposal utilizing a hydraulic discharge pipeline.
(4) Negative cost differential values reflect that it is more cost effective to transport and dispose dredged sediments at the Palos Verdes Shelf versus the comparison disposal site.

Table G3
Disposal Unit Cost Comparisons for Dredged Sediments Originating from the Upper Newport Bay. Values are given in dollars per cubic yard (and do not include mob/demob costs)

Equipment	PV Shelf ($/cy)	LA-2 ($/cy)	LA-3 ($/cy)	In-Bay ($/cy)	PV Shelf vs. LA-2 ($/cy)	PV Shelf vs. LA-3 ($/cy)	PV Shelf vs. In-Bay ($/cy)
Hopper Dredge[1]	10.66	9.84	4.70	n/a	0.82	5.96	n/a
Tug & Scow[2]	6.23	6.14	4.27	n/a	0.09	1.96	n/a
Hydraulic Pipeline	n/a	n/a	n/a	n/a	n/a	n/a	n/a

(1) Estimates are based on the unit costs to dredge, transport, and dispose the dredged material.
(2) Estimates are based on the unit cost to dredge ($3.00/cy), transport and dispose (slurry) the dredged material.

Table G4
Unit Cost to Excavate, Transport, and Dispose Dredged Sediments Originating from Portuguese Bend, Rancho Palos Verdes. Values are given in dollars per cubic yard (does not include mob/demob costs)

Equipment	PV Shelf ($/cy)	LA-2 ($/cy)	LA-3 ($/cy)	In-Bay ($/cy)	PV Shelf vs. LA-2 ($/cy)	PV Shelf vs. LA-3 ($/cy)	PV Shelf vs. In-Bay ($/cy)
Hopper Dredge	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Tug & Scow[1]	4.47 to 5.43	n/a	n/a	n/a	n/a	n/a	n/a
Hydraulic Pipeline	n/a	n/a	n/a	n/a	n/a	n/a	n/a

(1) Unit cost varies as a function of the volume of sediments to be excavated and disposed (slurry). The unit cost estimate is computed based on sediment volumes ranging from 1,000,000 cy to 8,000,000 cy.

Table G5
Unit Cost Estimates for Dredge Material Volumes Less Than 1,000,000 cy, Originating from the Port of Los Angeles and Port of Long Beach. Unit cost includes the cost to dredge, transport, and dispose material at White Point

DREDGE SITE	DREDGE EQUIPMENT	VOLUME (CY)	UNIT COST W/O MOB ($/CY)	UNIT COST WITH MOB ($/CY)
PORT OF LOS ANGELES	CLAMSHELL - TUG & SCOW[1]	750000	4.50	5.57
		500000	4.75	6.35
		250000	5.00	8.20
PORT OF LOS ANGELES	HOPPER[2]	750000	3.85	4.85
		500000	3.85	5.35
		250000	3.85	6.85
PORT OF LONG BEACH	CLAMSHELL - TUG & SCOW[1]	750000	4.96	6.02
		500000	5.21	6.81
		250000	5.46	8.66
PORT OF LONG BEACH	HOPPER[2]	750000	4.69	5.69
		500000	4.69	6.19
		250000	4.69	7.69

(1) Mobilization and Demobilization cost is estimated at $800,000.
(2) Mobilization and Demobilization cost is estimated at $750,000.

Table G6
Construction cost to dredge, transport, and dispose sediment from the AIII offshore borrow area to the Palos Verdes Shelf disposal site, employing a hopper dredge. Estimates include construction supervision and administration cost[1]

Dredge Volume (cy)	Mob/Demob Est. Cost ($)	Dredge/ Trnspt Est. Cost ($)	Total Estimated Construction Cost ($)	Unit Cost w/o Mob ($/cy)	Unit Cost with Mob ($/cy)	Construct S&A Cost ($)
1000000	750000	4687500	5437500	4.69	5.44	342563
1500000	750000	7031250	7781250	4.69	5.19	490219
2000000	750000	9375000	10125000	4.69	5.06	637875
2500000	750000	11718750	12468750	4.69	4.99	785531
3000000	750000	14062500	14812500	4.69	4.94	933188
3500000	750000	16406250	17156250	4.69	4.90	1080844
4000000	750000	18750000	19500000	4.69	4.88	1228500
4500000	750000	21093750	21843750	4.69	4.85	1376156
5000000	750000	23437500	24187500	4.69	4.84	1523813
5500000	750000	25781250	26531250	4.69	4.82	1671469
6000000	750000	28125000	28875000	4.69	4.81	1819125
6500000	750000	30468750	31218750	4.69	4.80	1966781
7000000	750000	32812500	33562500	4.69	4.79	2114438
7500000	750000	35156250	35906250	4.69	4.79	2262094
8000000	750000	37500000	38250000	4.69	4.78	2409750

(1) Supervision & Administration cost is calculated as 6.30% of the total construction cost.

Table G7
Construction cost to dredge, transport, and dispose sediment from the Port of Long Beach's West Anchorage area to the Palos Verdes Shelf disposal site, employing a hopper dredge. Estimates include construction supervision and administration cost[1]

DREDGE VOLUME (CY)	MOB/DEMOB EST. COST ($)	DREDGE/ TRNSPT EST. COST ($)	TOTAL ESTIMATED CONSTRUCTION COST ($)	UNIT COST W/O MOB ($/CY)	UNIT COST WITH MOB ($/CY)	CONSTRUCT S&A COST ($)
1000000	750000	4826389	5576389	4.83	5.58	351313
1500000	750000	7239583	7989583	4.83	5.33	503344
2000000	750000	9652778	10402778	4.83	5.20	655375
2500000	750000	12065972	12815972	4.83	5.13	807406
3000000	750000	14479167	15229167	4.83	5.08	959438
3500000	750000	16892361	17642361	4.83	5.04	1111469
4000000	750000	19305556	20055556	4.83	5.01	1263500

(1) Supervision & Administration cost is calculated as 6.30% of the total construction cost.

Table G8
Assumptions for calculating the cost estimates for capping material originating from the AIII Offshore Borrow area and POLB's West Anchorage area

	OFFSHORE BORROW AREA	WEST ANCHORAGE AREA
Dredge Location	Offshore Borrow Area (AIII)	West Anchorage Area (POLB)
Disposal Area	Palos Verdes Shelf	Palos Verdes Shelf
Equipment & Capacity	Hopper Dredge (3600/1800 cy)	Hopper Dredge (3600/1800 cy)
Dredge Cost	$45,000 per day	$45,000 per day
Distance to PV Shelf	7.5 nm	8.0 nm
Borrow Area Depth	-80 ft MLLW	-45 ft MLLW
Available Material	unlimited	4,000,000 cy

Table G9
Preliminary cost estimate to dredge sediments with a hopper dredge from the Port of Los Angeles and transport and dispose the dredged sediments offshore of White Point (Palos Verdes Shelf). Cost estimate matrix does not include mobilization/demobilization, supervision and administration, engineering and design, or contingency costs

HOPPER DREDGE*
Port of Los Angeles - Angel's Gate
to
Palos Verdes Shelf (White Point)

Dredge[1] Volume (cy)	Distance to PV Shelf (nm)	Cost Per Day ($)	Hopper[2] Capacity (cy)	No. of Hrs. To Capacity (hrs)	Average Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (hrs)	No. Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Total Cost Estimate ($)
1000000	4.50	45000.00	1800.00	2.00	7.50	1.20	0.50	3.70	6.49	11675.68	85.65	3854167
1500000	4.50	45000.00	1800.00	2.00	7.50	1.20	0.50	3.70	6.49	11675.68	128.47	5781250
2000000	4.50	45000.00	1800.00	2.00	7.50	1.20	0.50	3.70	6.49	11675.68	171.30	7708333
2500000	4.50	45000.00	1800.00	2.00	7.50	1.20	0.50	3.70	6.49	11675.68	214.12	9635417
3000000	4.50	45000.00	1800.00	2.00	7.50	1.20	0.50	3.70	6.49	11675.68	256.94	11562500
3500000	4.50	45000.00	1800.00	2.00	7.50	1.20	0.50	3.70	6.49	11675.68	299.77	13489583
4000000	4.50	45000.00	1800.00	2.00	7.50	1.20	0.50	3.70	6.49	11675.68	342.59	15416667
4500000	4.50	45000.00	1800.00	2.00	7.50	1.20	0.50	3.70	6.49	11675.68	385.42	17343750
5000000	4.50	45000.00	1800.00	2.00	7.50	1.20	0.50	3.70	6.49	11675.68	428.24	19270833
5500000	4.50	45000.00	1800.00	2.00	7.50	1.20	0.50	3.70	6.49	11675.68	471.06	21197917
6000000	4.50	45000.00	1800.00	2.00	7.50	1.20	0.50	3.70	6.49	11675.68	513.89	23125000
6500000	4.50	45000.00	1800.00	2.00	7.50	1.20	0.50	3.70	6.49	11675.68	556.71	25052083
7000000	4.50	45000.00	1800.00	2.00	7.50	1.20	0.50	3.70	6.49	11675.68	599.54	26979167
7500000	4.50	45000.00	1800.00	2.00	7.50	1.20	0.50	3.70	6.49	11675.68	642.36	28906250
8000000	4.50	45000.00	1800.00	2.00	7.50	1.20	0.50	3.70	6.49	11675.68	685.19	30833333

*Operations are 24 hours per day.
[1] In-Hopper sediment volume.
[2] 3600 cy Hopper Dredge with an In-Hopper sediment volume of 1800 cy.

Table G10
Preliminary cost estimate to dredge sediments with a hopper dredge from the Port of Long Beach and transport and dispose the dredged sediments offshore of White Point (Palos Verdes Shelf). Cost estimate matrix does not include mobilization/demobilization, supervision and administration, engineering and design, or contingency costs

HOPPER DREDGE*
Port of Long Beach - Queen's Gate
to
Palos Verdes Shelf (White Point)

Dredge[1] Volume (cy)	Distance to PV Shelf (nm)	Cost Per Day ($)	Hopper[2] Capacity (cy)	No. of Hrs. To Capacity (hrs)	Average Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (hrs)	No. Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Total Cost Estimate ($)
1000000	7.50	45000.00	1800.00	2.00	7.50	2.00	0.50	4.50	5.33	9600.00	104.17	4687500
1500000	7.50	45000.00	1800.00	2.00	7.50	2.00	0.50	4.50	5.33	9600.00	156.25	7031250
2000000	7.50	45000.00	1800.00	2.00	7.50	2.00	0.50	4.50	5.33	9600.00	208.33	9375000
2500000	7.50	45000.00	1800.00	2.00	7.50	2.00	0.50	4.50	5.33	9600.00	260.42	11718750
3000000	7.50	45000.00	1800.00	2.00	7.50	2.00	0.50	4.50	5.33	9600.00	312.50	14062500
3500000	7.50	45000.00	1800.00	2.00	7.50	2.00	0.50	4.50	5.33	9600.00	364.58	16406250
4000000	7.50	45000.00	1800.00	2.00	7.50	2.00	0.50	4.50	5.33	9600.00	416.67	18750000
4500000	7.50	45000.00	1800.00	2.00	7.50	2.00	0.50	4.50	5.33	9600.00	468.75	21093750
5000000	7.50	45000.00	1800.00	2.00	7.50	2.00	0.50	4.50	5.33	9600.00	520.83	23437500
5500000	7.50	45000.00	1800.00	2.00	7.50	2.00	0.50	4.50	5.33	9600.00	572.92	25781250
6000000	7.50	45000.00	1800.00	2.00	7.50	2.00	0.50	4.50	5.33	9600.00	625.00	28125000
6500000	7.50	45000.00	1800.00	2.00	7.50	2.00	0.50	4.50	5.33	9600.00	677.08	30468750
7000000	7.50	45000.00	1800.00	2.00	7.50	2.00	0.50	4.50	5.33	9600.00	729.17	32812500
7500000	7.50	45000.00	1800.00	2.00	7.50	2.00	0.50	4.50	5.33	9600.00	781.25	35156250
8000000	7.50	45000.00	1800.00	2.00	7.50	2.00	0.50	4.50	5.33	9600.00	833.33	37500000

*Operations are 24 hours per day.
[1] In-Hopper sediment volume.
[2] 3600 cy Hopper Dredge with an In-Hopper sediment volume of 1800 cy.

Table G11
Preliminary cost estimate to dredge sediments with a hopper dredge from the Upper Newport Bay and transport and dispose the dredged sediments offshore of White Point (Palos Verdes Shelf). Cost estimate matrix does not include mobilization/demobilization, supervision and administration, engineering and design, or contingency costs

HOPPER DREDGE*
Upper Newport Bay - Orange County
to
Palos Verdes Shelf (White Point)

Dredge[1] Volume (cy)	Distance to PV Shelf (nm)	Cost Per Day ($)	Hopper[2] Capacity (cy)	No. of Hrs. To Capacity (hrs)	Average Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (hrs)	No. Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Total Cost Estimate ($)
1000000	29.00	45000.00	1800.00	2.00	7.50	7.73	0.50	10.23	2.35	4221.50	236.88	10659722
1500000	29.00	45000.00	1800.00	2.00	7.50	7.73	0.50	10.23	2.35	4221.50	355.32	15989583
2000000	29.00	45000.00	1800.00	2.00	7.50	7.73	0.50	10.23	2.35	4221.50	473.77	21319444
2500000	29.00	45000.00	1800.00	2.00	7.50	7.73	0.50	10.23	2.35	4221.50	592.21	26649306
3000000	29.00	45000.00	1800.00	2.00	7.50	7.73	0.50	10.23	2.35	4221.50	710.65	31979167
3500000	29.00	45000.00	1800.00	2.00	7.50	7.73	0.50	10.23	2.35	4221.50	829.09	37309028
4000000	29.00	45000.00	1800.00	2.00	7.50	7.73	0.50	10.23	2.35	4221.50	947.53	42638889
4500000	29.00	45000.00	1800.00	2.00	7.50	7.73	0.50	10.23	2.35	4221.50	1065.97	47968750
5000000	29.00	45000.00	1800.00	2.00	7.50	7.73	0.50	10.23	2.35	4221.50	1184.41	53298611
5500000	29.00	45000.00	1800.00	2.00	7.50	7.73	0.50	10.23	2.35	4221.50	1302.85	58628472
6000000	29.00	45000.00	1800.00	2.00	7.50	7.73	0.50	10.23	2.35	4221.50	1421.30	63958333
6500000	29.00	45000.00	1800.00	2.00	7.50	7.73	0.50	10.23	2.35	4221.50	1539.74	69288194
7000000	29.00	45000.00	1800.00	2.00	7.50	7.73	0.50	10.23	2.35	4221.50	1658.18	74618056
7500000	29.00	45000.00	1800.00	2.00	7.50	7.73	0.50	10.23	2.35	4221.50	1776.62	79947917
8000000	29.00	45000.00	1800.00	2.00	7.50	7.73	0.50	10.23	2.35	4221.50	1895.06	85277778

*Operations are 24 hours per day.
[1] In-Hopper sediment volume.
[2] 3600 cy Hopper Dredge with an In-Hopper sediment volume of 1800 cy.

Table G12
Dredging Portuguese Bend with a hopper dredge for the purpose of providing capping material at White Point is not practical, therefore a cost estimate was not computed for this alternative

HOPPER DREDGE*
Palos Verdes Peninsula - Portuguese Bend
to
Palos Verdes Shelf (White Point)

Dredge[1] Volume (cy)	Distance to PV Shelf (nm)	Cost Per Day ($)	Hopper[2] Capacity (cy)	No. of Hrs. To Capacity (hrs)	Average Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (hrs)	No. Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Total Cost Estimate ($)
NOT APPLICABLE												

*Operations are 24 hours per day.
[1] In-Hopper sediment volume.
[2] 3600 cy Hopper Dredge with an In-Hopper sediment volume of 1800 cy.

Table G13
Preliminary cost estimate to dredge sediments with a hopper dredge from the AIII Offshore Borrow Area and transport and dispose the dredged sediments offshore of White Point (Palos Verdes Shelf). Cost estimate matrix does not include mobilization/demobilization, supervision and administration, engineering and design, or contingency costs

HOPPER DREDGE*
San Pedro Bay - Offshore Borrow Area (AIII)
to
Palos Verdes Shelf (White Point)

Dredge[1] Volume (cy)	Distance to PV Shelf (nm)	Cost Per Day ($)	Hopper[2] Capacity (cy)	No. of Hrs. To Capacity (hrs)	Average Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (hrs)	No. Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Total Cost Estimate ($)
1000000	7.50	45000.00	1800.00	2.00	7.50	2.00	0.50	4.50	5.33	9600.00	104.17	4687500
1500000	7.50	45000.00	1800.00	2.00	7.50	2.00	0.50	4.50	5.33	9600.00	156.25	7031250
2000000	7.50	45000.00	1800.00	2.00	7.50	2.00	0.50	4.50	5.33	9600.00	208.33	9375000
2500000	7.50	45000.00	1800.00	2.00	7.50	2.00	0.50	4.50	5.33	9600.00	260.42	11718750
3000000	7.50	45000.00	1800.00	2.00	7.50	2.00	0.50	4.50	5.33	9600.00	312.50	14062500
3500000	7.50	45000.00	1800.00	2.00	7.50	2.00	0.50	4.50	5.33	9600.00	364.58	16406250
4000000	7.50	45000.00	1800.00	2.00	7.50	2.00	0.50	4.50	5.33	9600.00	416.67	18750000
4500000	7.50	45000.00	1800.00	2.00	7.50	2.00	0.50	4.50	5.33	9600.00	468.75	21093750
5000000	7.50	45000.00	1800.00	2.00	7.50	2.00	0.50	4.50	5.33	9600.00	520.83	23437500
5500000	7.50	45000.00	1800.00	2.00	7.50	2.00	0.50	4.50	5.33	9600.00	572.92	25781250
6000000	7.50	45000.00	1800.00	2.00	7.50	2.00	0.50	4.50	5.33	9600.00	625.00	28125000
6500000	7.50	45000.00	1800.00	2.00	7.50	2.00	0.50	4.50	5.33	9600.00	677.08	30468750
7000000	7.50	45000.00	1800.00	2.00	7.50	2.00	0.50	4.50	5.33	9600.00	729.17	32812500
7500000	7.50	45000.00	1800.00	2.00	7.50	2.00	0.50	4.50	5.33	9600.00	781.25	35156250
8000000	7.50	45000.00	1800.00	2.00	7.50	2.00	0.50	4.50	5.33	9600.00	833.33	37500000

*Operations are 24 hours per day.
[1] In-Hopper sediment volume.
[2] 3600 cy Hopper Dredge with an In-Hopper sediment volume of 1800 cy.

Table G14
Preliminary cost estimate to dredge sediments with a hopper dredge from the West Anchorage Area (Port of Long Beach) and transport and dispose the dredged sediments offshore of White Point (Palos Verdes Shelf). Cost estimate matrix does not include mobilization/demobilization, supervision and administration, engineering and design, or contingency costs

HOPPER DREDGE*
Port of Long Beach - West Anchorage Area
to
Palos Verdes Shelf (White Point)

Dredge[1] Volume (cy)	Distance to PV Shelf (nm)	Cost Per Day ($)	Hopper[2] Capacity (cy)	No. of Hrs. To Capacity (hrs)	Average Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (hrs)	No. Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Total Cost Estimate ($)
1000000	8.00	45000.00	1800.00	2.00	7.50	2.13	0.50	4.63	5.18	9323.74	107.25	4826389
1500000	8.00	45000.00	1800.00	2.00	7.50	2.13	0.50	4.63	5.18	9323.74	160.88	7239583
2000000	8.00	45000.00	1800.00	2.00	7.50	2.13	0.50	4.63	5.18	9323.74	214.51	9652778
2500000	8.00	45000.00	1800.00	2.00	7.50	2.13	0.50	4.63	5.18	9323.74	268.13	12065972
3000000	8.00	45000.00	1800.00	2.00	7.50	2.13	0.50	4.63	5.18	9323.74	321.76	14479167
3500000	8.00	45000.00	1800.00	2.00	7.50	2.13	0.50	4.63	5.18	9323.74	375.39	16892361
4000000	8.00	45000.00	1800.00	2.00	7.50	2.13	0.50	4.63	5.18	9329.74	429.01	19305556

*Operations are 24 hours per day.
[1] In-Hopper sediment volume.
[2] 3600 cy Hopper Dredge with an In-Hopper sediment volume of 1800 cy.

Table G15

Preliminary cost estimate to dredge sediments with a hopper dredge from the Port of Los Angeles and transport and dispose the dredged sediments at the LA-2 Ocean Disposal site. Cost estimate matrix does not include mobilization/demobilization, supervision and administration, engineering and design, or contingency costs

HOPPER DREDGE*
Port of Los Angeles - Angel's Gate
to
LA-2 Ocean Disposal Site

Dredge[1] Volume (cy)	Distance to LA-2 (nm)	Cost Per Day ($)	Hopper[2] Capacity (cy)	No. of Hrs. To Capacity (hrs)	Average Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (hrs)	No. Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Total Cost Estimate ($)
1000000	6.00	45000.00	1800.00	2.00	7.50	1.60	0.25	3.85	6.23	11220.78	89.12	4010417
1500000	6.00	45000.00	1800.00	2.00	7.50	1.60	0.25	3.85	6.23	11220.78	133.68	6015625
2000000	6.00	45000.00	1800.00	2.00	7.50	1.60	0.25	3.85	6.23	11220.78	178.24	8020833
2500000	6.00	45000.00	1800.00	2.00	7.50	1.60	0.25	3.85	6.23	11220.78	222.80	10026042
3000000	6.00	45000.00	1800.00	2.00	7.50	1.60	0.25	3.85	6.23	11220.78	267.36	12031250
3500000	6.00	45000.00	1800.00	2.00	7.50	1.60	0.25	3.85	6.23	11220.78	311.92	14036458
4000000	6.00	45000.00	1800.00	2.00	7.50	1.60	0.25	3.85	6.23	11220.78	356.48	16041667
4500000	6.00	45000.00	1800.00	2.00	7.50	1.60	0.25	3.85	6.23	11220.78	401.04	18046875
5000000	6.00	45000.00	1800.00	2.00	7.50	1.60	0.25	3.85	6.23	11220.78	445.60	20052083
5500000	6.00	45000.00	1800.00	2.00	7.50	1.60	0.25	3.85	6.23	11220.78	490.16	22057292
6000000	6.00	45000.00	1800.00	2.00	7.50	1.60	0.25	3.85	6.23	11220.78	534.72	24062500
6500000	6.00	45000.00	1800.00	2.00	7.50	1.60	0.25	3.85	6.23	11220.78	579.28	26067708
7000000	6.00	45000.00	1800.00	2.00	7.50	1.60	0.25	3.85	6.23	11220.78	623.84	28072917
7500000	6.00	45000.00	1800.00	2.00	7.50	1.60	0.25	3.85	6.23	11220.78	668.40	30078125
8000000	6.00	45000.00	1800.00	2.00	7.50	1.60	0.25	3.85	6.23	11220.78	712.96	32083333

*Operations are 24 hours per day.
[1] In-Hopper sediment volume.
[2] 3600 cy Hopper Dredge with an In-Hopper sediment volume of 1800 cy.

Table G16
Preliminary cost estimate to dredge sediments with a hopper dredge from the Port of Long Beach and transport and dispose the dredged sediments at the LA-2 Ocean Disposal site. Cost estimate matrix does not include mobilization/demobilization, supervision and administration, engineering and design, or contingency costs

HOPPER DREDGE*
Port of Long Beach - Queen's Gate
to
LA-2 Ocean Disposal Site

Dredge[1] Volume (cy)	Distance to LA-2 (nm)	Cost Per Day ($)	Hopper[2] Capacity (cy)	No. of Hrs. To Capacity (hrs)	Average Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (hrs)	No. Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Total Cost Estimate ($)
1000000	8.50	45000.00	1800.00	2.00	7.50	2.27	0.25	4.52	5.31	9564.58	104.55	4704861
1500000	8.50	45000.00	1800.00	2.00	7.50	2.27	0.25	4.52	5.31	9564.58	156.83	7057292
2000000	8.50	45000.00	1800.00	2.00	7.50	2.27	0.25	4.52	5.31	9564.58	209.10	9409722
2500000	8.50	45000.00	1800.00	2.00	7.50	2.27	0.25	4.52	5.31	9564.58	261.38	11762153
3000000	8.50	45000.00	1800.00	2.00	7.50	2.27	0.25	4.52	5.31	9564.58	313.66	14114583
3500000	8.50	45000.00	1800.00	2.00	7.50	2.27	0.25	4.52	5.31	9564.58	365.93	16467014
4000000	8.50	45000.00	1800.00	2.00	7.50	2.27	0.25	4.52	5.31	9564.58	418.21	18819444
4500000	8.50	45000.00	1800.00	2.00	7.50	2.27	0.25	4.52	5.31	9564.58	470.49	21171875
5000000	8.50	45000.00	1800.00	2.00	7.50	2.27	0.25	4.52	5.31	9564.58	522.76	23524306
5500000	8.50	45000.00	1800.00	2.00	7.50	2.27	0.25	4.52	5.31	9564.58	575.04	25876736
6000000	8.50	45000.00	1800.00	2.00	7.50	2.27	0.25	4.52	5.31	9564.58	627.31	28229167
6500000	8.50	45000.00	1800.00	2.00	7.50	2.27	0.25	4.52	5.31	9564.58	679.59	30581597
7000000	8.50	45000.00	1800.00	2.00	7.50	2.27	0.25	4.52	5.31	9564.58	731.87	32934028
7500000	8.50	45000.00	1800.00	2.00	7.50	2.27	0.25	4.52	5.31	9564.58	784.14	35286458
8000000	8.50	45000.00	1800.00	2.00	7.50	2.27	0.25	4.52	5.31	9564.58	836.42	37638889

*Operations are 24 hours per day.
[1] In-Hopper sediment volume.
[2] 3600 cy Hopper Dredge with an In-Hopper sediment volume of 1800 cy.

Table G17
Preliminary cost estimate to dredge sediments with a hopper dredge from the Upper Newport Bay and transport and dispose the dredged sediments at the LA-2 Ocean Disposal site. Cost estimate matrix does not include mobilization/demobilization, supervision and administration, engineering and design, or contingency costs

HOPPER DREDGE*
Upper Newport Bay - Orange County
to
LA-2 Ocean Disposal Site

Dredge[1] Volume (cy)	Distance to LA-2 (nm)	Cost Per Day ($)	Hopper[2] Capacity (cy)	No. of Hrs. To Capacity (hrs)	Average Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (hrs)	No. Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Total Cost Estimate ($)
1000000	27.00	45000.00	1800.00	2.00	7.50	7.20	0.25	9.45	2.54	4571.43	218.75	9843750
1500000	27.00	45000.00	1800.00	2.00	7.50	7.20	0.25	9.45	2.54	4571.43	328.13	14765625
2000000	27.00	45000.00	1800.00	2.00	7.50	7.20	0.25	9.45	2.54	4571.43	437.50	19687500
2500000	27.00	45000.00	1800.00	2.00	7.50	7.20	0.25	9.45	2.54	4571.43	546.88	24609375
3000000	27.00	45000.00	1800.00	2.00	7.50	7.20	0.25	9.45	2.54	4571.43	656.25	29531250
3500000	27.00	45000.00	1800.00	2.00	7.50	7.20	0.25	9.45	2.54	4571.43	765.63	34453125
4000000	27.00	45000.00	1800.00	2.00	7.50	7.20	0.25	9.45	2.54	4571.43	875.00	39375000
4500000	27.00	45000.00	1800.00	2.00	7.50	7.20	0.25	9.45	2.54	4571.43	984.38	44296875
5000000	27.00	45000.00	1800.00	2.00	7.50	7.20	0.25	9.45	2.54	4571.43	1093.75	49218750
5500000	27.00	45000.00	1800.00	2.00	7.50	7.20	0.25	9.45	2.54	4571.43	1203.13	54140625
6000000	27.00	45000.00	1800.00	2.00	7.50	7.20	0.25	9.45	2.54	4571.43	1312.50	59062500
6500000	27.00	45000.00	1800.00	2.00	7.50	7.20	0.25	9.45	2.54	4571.43	1421.88	63984375
7000000	27.00	45000.00	1800.00	2.00	7.50	7.20	0.25	9.45	2.54	4571.43	1531.25	68906250
7500000	27.00	45000.00	1800.00	2.00	7.50	7.20	0.25	9.45	2.54	4571.43	1640.63	73828125
8000000	27.00	45000.00	1800.00	2.00	7.50	7.20	0.25	9.45	2.54	4571.43	1750.00	78750000

*Operations are 24 hours per day.
[1] In-Hopper sediment volume.
[2] 3600 cy Hopper Dredge with an In-Hopper sediment volume of 1800 cy.

Table G18
Dredging Portuguese Bend with a hopper dredge for the purpose of disposing the dredge material at the LA-2 Ocean Disposal site is not practical, therefore a cost estimate was not computed for this scenario

HOPPER DREDGE*
Palos Verdes Peninsula - Portuguese Bend
to
LA-2 Ocean Disposal Site

Dredge[1] Volume (cy)	Distance to PV Shelf (nm)	Cost Per Day ($)	Hopper[2] Capacity (cy)	No. of Hrs. To Capacity (hrs)	Average Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (hrs)	No. Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Total Cost Estimate ($)
NOT APPLICABLE												

*Operations are 24 hours per day.
[1] In-Hopper sediment volume.
[2] 3600 cy Hopper Dredge with an In-Hopper sediment volume of 1800 cy.

Table G19
Dredging the Port of Los Angeles with a hopper dredge for the purpose of disposing the dredged material at the LA-3 Ocean Disposal site is not practical, therefore a cost estimate was not computed for this scenario

HOPPER DREDGE*
Port of Los Angeles - Angel's Gate
to
LA-3 Ocean Disposal Site

Dredge[1] Volume (cy)	Distance to PV Shelf (nm)	Cost Per Day ($)	Hopper[2] Capacity (cy)	No. of Hrs. To Capacity (hrs)	Average Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (hrs)	No. Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Total Cost Estimate ($)
NOT APPLICABLE												

*Operations are 24 hours per day.
[1] In-Hopper sediment volume.
[2] 3600 cy Hopper Dredge with an In-Hopper sediment volume of 1800 cy.

Table G20
Dredging the Port of Long Beach with a hopper dredge for the purpose of disposing the dredged material at the LA-3 Ocean Disposal site is not practical, therefore a cost estimate was not computed for this scenario

HOPPER DREDGE*
Port of Long Beach - Queen's Gate
to
LA-3 Ocean Disposal Site

Dredge[1] Volume (cy)	Distance to PV Shelf (nm)	Cost Per Day ($)	Hopper[2] Capacity (cy)	No. of Hrs. To Capacity (hrs)	Average Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (hrs)	No. Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Total Cost Estimate ($)
NOT APPLICABLE												

*Operations are 24 hours per day.
[1] In-Hopper sediment volume.
[2] 3600 cy Hopper Dredge with an In-Hopper sediment volume of 1800 cy.

Table G21
Preliminary cost estimate to dredge sediments with a hopper dredge from the Upper Newport Bay and transport and dispose the dredged sediments at the LA-3 Ocean Disposal site. Cost estimate matrix does not include mobilization/demobilization, supervision and administration, engineering and design, or contingency costs

HOPPER DREDGE*
Upper Newport Bay - Orange County
to
LA-3 Ocean Disposal Site

Dredge[1] Volume (cy)	Distance to LA-3 (nm)	Cost Per Day ($)	Hopper[2] Capacity (cy)	No. of Hrs. To Capacity (hrs)	Average Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (hrs)	No. Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Total Cost Estimate ($)
1000000	8.50	45000.00	1800.00	2.00	7.50	2.27	0.25	4.52	5.31	9564.58	104.55	4704861
1500000	8.50	45000.00	1800.00	2.00	7.50	2.27	0.25	4.52	5.31	9564.58	156.83	7057292
2000000	8.50	45000.00	1800.00	2.00	7.50	2.27	0.25	4.52	5.31	9564.58	209.10	9409722
2500000	8.50	45000.00	1800.00	2.00	7.50	2.27	0.25	4.52	5.31	9564.58	261.38	11762153
3000000	8.50	45000.00	1800.00	2.00	7.50	2.27	0.25	4.52	5.31	9564.58	313.66	14114583
3500000	8.50	45000.00	1800.00	2.00	7.50	2.27	0.25	4.52	5.31	9564.58	365.93	16467014
4000000	8.50	45000.00	1800.00	2.00	7.50	2.27	0.25	4.52	5.31	9564.58	418.21	18819444
4500000	8.50	45000.00	1800.00	2.00	7.50	2.27	0.25	4.52	5.31	9564.58	470.49	21171875
5000000	8.50	45000.00	1800.00	2.00	7.50	2.27	0.25	4.52	5.31	9564.58	522.76	23524306
5500000	8.50	45000.00	1800.00	2.00	7.50	2.27	0.25	4.52	5.31	9564.58	575.04	25876736
6000000	8.50	45000.00	1800.00	2.00	7.50	2.27	0.25	4.52	5.31	9564.58	627.31	28229167
6500000	8.50	45000.00	1800.00	2.00	7.50	2.27	0.25	4.52	5.31	9564.58	679.59	30581597
7000000	8.50	45000.00	1800.00	2.00	7.50	2.27	0.25	4.52	5.31	9564.58	731.87	32934028
7500000	8.50	45000.00	1800.00	2.00	7.50	2.27	0.25	4.52	5.31	9564.58	784.14	35286458
8000000	8.50	45000.00	1800.00	2.00	7.50	2.27	0.25	4.52	5.31	9564.58	836.42	37638889

*Operations are 24 hours per day.
[1] In-Hopper sediment volume.
[2] 3600 cy Hopper Dredge with an In-Hopper sediment volume of 1800 cy.

Table G22
Dredging Portuguese Bend with a hopper dredge for the purpose of disposing the dredge material at the LA-3 Ocean Disposal site is not practical, therefore a cost estimate was not computed for this scenario

HOPPER DREDGE*
Palos Verdes Peninsula - Portuguese Bend
to
LA-3 Ocean Disposal Site

Dredge[1] Volume (cy)	Distance to PV Shelf (nm)	Cost Per Day ($)	Hopper[2] Capacity (cy)	No. of Hrs. To Capacity (hrs)	Average Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (hrs)	No. Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Total Cost Estimate ($)
NOT APPLICABLE												

*Operations are 24 hours per day.
[1] In-Hopper sediment volume.
[2] 3600 cy Hopper Dredge with an In-Hopper sediment volume of 1800 cy.

Table G23
Preliminary cost estimate to dredge sediments with a hopper dredge from the Port of Los Angeles and transport and dispose the dredged sediments at an In-Harbor disposal site. Cost estimate matrix does not include mobilization/demobilization, supervision and administration, engineering and design, or contingency costs

HOPPER DREDGE*
Port of Los Angeles - Angel's Gate
to
In-Harbor Disposal Site

Dredge[1] Volume (cy)	Distance to In-Bay (nm)	Cost Per Day ($)	Hopper[2] Capacity (cy)	No. of Hrs. To Capacity (hrs)	Average Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (hrs)	No. Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Total Cost Estimate ($)
1000000	0.50	45000.00	1800.00	2.00	7.50	0.13	0.25	2.38	10.07	18125.87	55.17	2482639
1500000	0.50	45000.00	1800.00	2.00	7.50	0.13	0.25	2.38	10.07	18125.87	82.75	3723958
2000000	0.50	45000.00	1800.00	2.00	7.50	0.13	0.25	2.38	10.07	18125.87	110.34	4965278
2500000	0.50	45000.00	1800.00	2.00	7.50	0.13	0.25	2.38	10.07	18125.87	137.92	6206597
3000000	0.50	45000.00	1800.00	2.00	7.50	0.13	0.25	2.38	10.07	18125.87	165.51	7447917
3500000	0.50	45000.00	1800.00	2.00	7.50	0.13	0.25	2.38	10.07	18125.87	193.09	8689236
4000000	0.50	45000.00	1800.00	2.00	7.50	0.13	0.25	2.38	10.07	18125.87	220.68	9930556
4500000	0.50	45000.00	1800.00	2.00	7.50	0.13	0.25	2.38	10.07	18125.87	248.26	11171875
5000000	0.50	45000.00	1800.00	2.00	7.50	0.13	0.25	2.38	10.07	18125.87	275.85	12413194
5500000	0.50	45000.00	1800.00	2.00	7.50	0.13	0.25	2.38	10.07	18125.87	303.43	13654514
6000000	0.50	45000.00	1800.00	2.00	7.50	0.13	0.25	2.38	10.07	18125.87	331.02	14895833
6500000	0.50	45000.00	1800.00	2.00	7.50	0.13	0.25	2.38	10.07	18125.87	358.60	16137153
7000000	0.50	45000.00	1800.00	2.00	7.50	0.13	0.25	2.38	10.07	18125.87	386.19	17378472
7500000	0.50	45000.00	1800.00	2.00	7.50	0.13	0.25	2.38	10.07	18125.87	413.77	18619792
8000000	0.50	45000.00	1800.00	2.00	7.50	0.13	0.25	2.38	10.07	18125.87	441.36	19861111

*Operations are 24 hours per day.
[1] In-Hopper sediment volume.
[2] 3600 cy Hopper Dredge with an In-Hopper sediment volume of 1800 cy.

Table G24
Preliminary cost estimate to dredge sediments with a hopper dredge from the Port of Long Beach and transport and dispose the dredged sediments at an In-Harbor disposal site. Cost estimate matrix does not include mobilization/demobilization, supervision and administration, engineering and design, or contingency costs

HOPPER DREDGE*
Port of Long Beach - Queen's Gate
to
In-Harbor Disposal Site

Dredge[1] Volume (cy)	Distance to In-Bay (nm)	Cost Per Day ($)	Hopper[2] Capacity (cy)	No. of Hrs. To Capacity (hrs)	Average Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (hrs)	No. Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Total Cost Estimate ($)
1000000	2.00	45000.00	1800.00	2.00	7.50	0.53	0.25	2.78	8.62	15520.96	64.43	2899306
1500000	2.00	45000.00	1800.00	2.00	7.50	0.53	0.25	2.78	8.62	15520.96	96.64	4348958
2000000	2.00	45000.00	1800.00	2.00	7.50	0.53	0.25	2.78	8.62	15520.96	128.86	5798611
2500000	2.00	45000.00	1800.00	2.00	7.50	0.53	0.25	2.78	8.62	15520.96	161.07	7248264
3000000	2.00	45000.00	1800.00	2.00	7.50	0.53	0.25	2.78	8.62	15520.96	193.29	8697917
3500000	2.00	45000.00	1800.00	2.00	7.50	0.53	0.25	2.78	8.62	15520.96	225.50	10147569
4000000	2.00	45000.00	1800.00	2.00	7.50	0.53	0.25	2.78	8.62	15520.96	257.72	11597222
4500000	2.00	45000.00	1800.00	2.00	7.50	0.53	0.25	2.78	8.62	15520.96	289.93	13046875
5000000	2.00	45000.00	1800.00	2.00	7.50	0.53	0.25	2.78	8.62	15520.96	322.15	14496528
5500000	2.00	45000.00	1800.00	2.00	7.50	0.53	0.25	2.78	8.62	15520.96	354.36	15946181
6000000	2.00	45000.00	1800.00	2.00	7.50	0.53	0.25	2.78	8.62	15520.96	386.57	17395833
6500000	2.00	45000.00	1800.00	2.00	7.50	0.53	0.25	2.78	8.62	15520.96	418.79	18845486
7000000	2.00	45000.00	1800.00	2.00	7.50	0.53	0.25	2.78	8.62	15520.96	451.00	20295139
7500000	2.00	45000.00	1800.00	2.00	7.50	0.53	0.25	2.78	8.62	15520.96	483.22	21744792
8000000	2.00	45000.00	1800.00	2.00	7.50	0.53	0.25	2.78	8.62	15520.96	515.43	23194444

*Operations are 24 hours per day.
[1] In-Hopper sediment volume.
[2] 3600 cy Hopper Dredge with an In-Hopper sediment volume of 1800 cy.

Table G25
Dredging Upper Newport Bay with a hopper dredge for the purpose of disposing the dredge material at an In-Harbor disposal site is not practical, therefore a cost estimate was not computed for this scenario

HOPPER DREDGE*
Upper Newport Bay - Orange County
to
In-Harbor Disposal Site

Dredge[1] Volume (cy)	Distance to PV Shelf (nm)	Cost Per Day ($)	Hopper[2] Capacity (cy)	No. of Hrs. To Capacity (hrs)	Average Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (hrs)	No. Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Total Cost Estimate ($)
NOT APPLICABLE												

*Operations are 24 hours per day.
[1] In-Hopper sediment volume.
[2] 3600 cy Hopper Dredge with an In-Hopper sediment volume of 1800 cy.

Table G26
Dredging Portuguese Bend with a hopper dredge for the purpose of disposing the dredge material at an In-Harbor disposal site is not practical, therefore a cost estimate was not computed for this scenario

HOPPER DREDGE*
Palos Verdes Peninsula - Portuguese Bend
to
In-Harbor Disposal Site

Dredge[1] Volume (cy)	Distance to PV Shelf (nm)	Cost Per Day ($)	Hopper[2] Capacity (cy)	No. of Hrs. To Capacity (hrs)	Average Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (hrs)	No. Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Total Cost Estimate ($)
NOT APPLICABLE												

*Operations are 24 hours per day.
[1] In-Hopper sediment volume.
[2] 3600 cy Hopper Dredge with an In-Hopper sediment volume of 1800 cy.

Table G27
Disposal cost comparisons for dredged sediments originating from the Port of Los Angeles. Values given in dollars and does not include mob/demob costs

HOPPER DREDGE
Port of Los Angeles - Angel's Gate
Dredged Material Disposal Cost Comparisons

Dredge Volume (cy)	PV Shelf Est. Cost ($)	LA-2 Est. Cost ($)	LA-3 Est. Cost ($)	In-Harbor Est. Cost ($)	PV Shelf vs. LA-2 (Delta $)	PV Shelf vs. LA-3 (Delta $)	PV Shelf vs. In-Bay (Delta $)
1000000	3854167	4010417	n/a	2482639	-156250	n/a	1371528
1500000	5781250	6015625	n/a	3723958	-234375	n/a	2057292
2000000	7708333	8020833	n/a	4965278	-312500	n/a	2743056
2500000	9635417	10026042	n/a	6206597	-390625	n/a	3428819
3000000	11562500	12031250	n/a	7447917	-468750	n/a	4114583
3500000	13489583	14036458	n/a	8689236	-546875	n/a	4800347
4000000	15416667	16041667	n/a	9930556	-625000	n/a	5486111
4500000	17343750	18046875	n/a	11171875	-703125	n/a	6171875
5000000	19270833	20052083	n/a	12413194	-781250	n/a	6857639
5500000	21197917	22057292	n/a	13654514	-859375	n/a	7543403
6000000	23125000	24062500	n/a	14895833	-937500	n/a	8229167
6500000	25052083	26067708	n/a	16137153	-1015625	n/a	8914931
7000000	26979167	28072917	n/a	17378472	-1093750	n/a	9600694
7500000	28906250	30078125	n/a	18619792	-1171875	n/a	10286458
8000000	30833333	32083333	n/a	19861111	-1250000	n/a	10972222

Table G28
Disposal cost comparisons for dredged sediments originating from the Port of Long Beach Values given in dollars and does not include mob/demob costs

HOPPER DREDGE
Port of Long Beach - Queen's Gate
Dredged Material Disposal Cost Comparisons

Dredge Volume (cy)	PV Shelf Est. Cost ($)	LA-2 Est. Cost ($)	LA-3 Est. Cost ($)	In-Harbor Est. Cost ($)	PV Shelf vs. LA-2 (Delta $)	PV Shelf vs. LA-3 (Delta $)	PV Shelf vs. In-Bay (Delta $)
1000000	4687500	4704861	n/a	2899306	-17361	n/a	1788194
1500000	7031250	7057292	n/a	4348958	-26042	n/a	2682292
2000000	9375000	9409722	n/a	5798611	-34722	n/a	3576389
2500000	11718750	11762153	n/a	7248264	-43403	n/a	4470486
3000000	14062500	14114583	n/a	8697917	-52083	n/a	5364583
3500000	16406250	16467014	n/a	10147569	-60764	n/a	6258681
4000000	18750000	18819444	n/a	11597222	-69444	n/a	7152778
4500000	21093750	21171875	n/a	13046875	-78125	n/a	8046875
5000000	23437500	23524306	n/a	14496528	-86806	n/a	8940972
5500000	25781250	25876736	n/a	15946181	-95486	n/a	9835069
6000000	28125000	28229167	n/a	17395833	-104167	n/a	10729167
6500000	30468750	30581597	n/a	18845486	-112847	n/a	11623264
7000000	32812500	32934028	n/a	20295139	-121528	n/a	12517361
7500000	35156250	35286458	n/a	21744792	-130208	n/a	13411458
8000000	37500000	37638889	n/a	23194444	-138889	n/a	14305556

Table G29
Disposal cost comparisons for dredged sediments originating from the Upper Newport Bay. Values given in dollars and does not include mob/demob costs

HOPPER DREDGE
Orange County - Upper Newport Bay
Dredged Material Disposal Cost Comparisons

Dredge Volume (cy)	PV Shelf Est. Cost ($)	LA-2 Est. Cost ($)	LA-3 Est. Cost ($)	In-Harbor Est. Cost ($)	PV Shelf vs. LA-2 (Delta $)	PV Shelf vs. LA-3 (Delta $)	PV Shelf vs. In-Bay (Delta $)
1000000	10659722	9843750	4704861	n/a	815972	5954861	n/a
1500000	15989583	14765625	7057292	n/a	1223958	8932292	n/a
2000000	21319444	19687500	9409722	n/a	1631944	11909722	n/a
2500000	26649306	24609375	11762153	n/a	2039931	14887153	n/a
3000000	31979167	29531250	14114583	n/a	2447917	17864583	n/a
3500000	37309028	34453125	16467014	n/a	2855903	20842014	n/a
4000000	42638889	39375000	18819444	n/a	3263889	23819444	n/a
4500000	47968750	44296875	21171875	n/a	3671875	26796875	n/a
5000000	53298611	49218750	23524306	n/a	4079861	29774306	n/a
5500000	58628472	54140625	25876736	n/a	4487847	32751736	n/a
6000000	63958333	59062500	28229167	n/a	4895833	35729167	n/a
6500000	69288194	63984375	30581597	n/a	5303819	38706597	n/a
7000000	74618056	68906250	32934028	n/a	5711806	41684028	n/a
7500000	79947917	73828125	35286458	n/a	6119792	44661458	n/a
8000000	85277778	78750000	37638889	n/a	6527778	47638889	n/a

Table G30
Disposal cost comparisons for dredged sediments originating from Portuguese Bend. Dredging Portuguese Bend with a hopper dredge is not practical, therefore no hopper dredge disposal cost comparisons are provided

HOPPER DREDGE Palos Verdes Peninsula Portuguese Bend							
Dredge Volume (cy)	PV Shelf Est. Cost ($)	LA-2 Est. Cost ($)	LA-3 Est. Cost ($)	In-Harbor Est. Cost ($)	PV Shelf vs. LA-2 (Delta $)	PV Shelf vs. LA-3 (Delta $)	PV Shelf vs. In-Bay (Delta $)
1000000	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1500000	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2000000	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2500000	n/a	n/a	n/a	n/a	n/a	n/a	n/a
3000000	n/a	n/a	n/a	n/a	n/a	n/a	n/a
3500000	n/a	n/a	n/a	n/a	n/a	n/a	n/a
4000000	n/a	n/a	n/a	n/a	n/a	n/a	n/a
4500000	n/a	n/a	n/a	n/a	n/a	n/a	n/a
5000000	n/a	n/a	n/a	n/a	n/a	n/a	n/a
5500000	n/a	n/a	n/a	n/a	n/a	n/a	n/a
6000000	n/a	n/a	n/a	n/a	n/a	n/a	n/a
6500000	n/a	n/a	n/a	n/a	n/a	n/a	n/a
7000000	n/a	n/a	n/a	n/a	n/a	n/a	n/a
7500000	n/a	n/a	n/a	n/a	n/a	n/a	n/a
8000000	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Table G31
Preliminary cost estimate to transport and dispose dredged sediments with a scow and tow from the Port of Los Angeles to the White Point (Palos Verdes Shelf) aquatic capping site. Cost estimate matrix does not include dredging, mobilization/demobilization, supervision and administration, engineering and design, or contingency costs

SCOW AND TOW*
Port of Los Angeles - Angel's Gate
to
Palos Verdes Shelf (White Point)

Dredge Volume (cy)	Distance to PV Shelf (nm)	No. of Large Scows	No. of Small Scows	No. of Large Tows	No. of Small Tows	Equip Cost Per Day ($)	Scow Capacity (cy)	No. of Hrs. To Capacity (hrs)	Avg Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (Trip) (hrs)	No. of Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Slurry Mod. Cost ($)	Total Cost Estimate ($)
1000000	4.50	0	2	1	2	13600.00	1500	2.50	8.00	1.13	1.50	2.63	6.48	9714.29	102.94	100000	1500000
1500000	4.50	0	2	1	2	13600.00	1500	2.50	8.00	1.13	1.50	2.63	6.48	9714.29	154.41	100000	2200000
2000000	4.50	0	2	1	2	13600.00	1500	2.50	8.00	1.13	1.50	2.63	6.48	9714.29	205.88	100000	2900000
2500000	4.50	0	2	1	2	13600.00	1500	2.50	8.00	1.13	1.50	2.63	6.48	9714.29	257.35	100000	3600000
3000000	4.50	0	2	1	2	13600.00	1500	2.50	8.00	1.13	1.50	2.63	6.48	9714.29	308.82	100000	4300000
3500000	4.50	0	2	1	2	13600.00	1500	2.50	8.00	1.13	1.50	2.63	6.48	9714.29	360.29	100000	5000000
4000000	4.50	0	2	1	2	13600.00	1500	2.50	8.00	1.13	1.50	2.63	6.48	9714.29	411.76	100000	5700000
4500000	4.50	0	2	1	2	13600.00	1500	2.50	8.00	1.13	1.50	2.63	6.48	9714.29	463.24	100000	6400000
5000000	4.50	0	2	1	2	13600.00	1500	2.50	8.00	1.13	1.50	2.63	6.48	9714.29	514.71	100000	7100000
5500000	4.50	0	2	1	2	13600.00	1500	2.50	8.00	1.13	1.50	2.63	6.48	9714.29	566.18	100000	7800000
6000000	4.50	0	2	1	2	13600.00	1500	2.50	8.00	1.13	1.50	2.63	6.48	9714.29	617.65	100000	8500000
6500000	4.50	0	2	1	2	13600.00	1500	2.50	8.00	1.13	1.50	2.63	6.48	9714.29	669.12	100000	9200000
7000000	4.50	0	2	1	2	13600.00	1500	2.50	8.00	1.13	1.50	2.63	6.48	9714.29	720.59	100000	9900000
7500000	4.50	0	2	1	2	13600.00	1500	2.50	8.00	1.13	1.50	2.63	6.48	9714.29	772.06	100000	10600000
8000000	4.50	0	2	1	2	13600.00	1500	2.50	8.00	1.13	1.50	2.63	6.48	9714.29	823.53	100000	11300000

* Assumes 17 hours per day operations and daily costs of: 1) Large Scow (2500 to 3000 cy) at $2,000/day; 2) Small Scow (1500 cy) at $800/day; 3) Large Tow at $6,000/day; and, 4) Small Tow at $3,000/day.

Table G32
Preliminary cost estimate to transport and dispose dredged sediments with a scow and tow from the Port of Long Beach to the White Point (Palos Verdes Shelf) aquatic capping site. Cost estimate matrix does not include dredging, mobilization/demobilization, supervision and administration, engineering and design, or contingency costs

SCOW AND TOW*
Port of Long Beach - Queen's Gate
to
Palos Verdes Shelf (White Point)

Dredge Volume (cy)	Distance to PV Shelf (nm)	No. of Large Scows	No. of Small Scows	No. of Large Tows	No. of Small Tows	Equip Cost Per Day ($)	Scow Capacity (cy)	No. of Hrs. To Capacity (hrs)	Avg Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (Trip) (hrs)	No. of Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Slurry Mod. Cost ($)	Total Cost Estimate ($)
1000000	7.50	2	0	2	1	19000.00	2500	4.17	6.00	2.50	1.50	4.00	4.08	10200.00	98.04	100000	1962745
1500000	7.50	2	0	2	1	19000.00	2500	4.17	6.00	2.50	1.50	4.00	4.08	10200.00	147.06	100000	2894118
2000000	7.50	2	0	2	1	19000.00	2500	4.17	6.00	2.50	1.50	4.00	4.08	10200.00	196.08	100000	3825490
2500000	7.50	2	0	2	1	19000.00	2500	4.17	6.00	2.50	1.50	4.00	4.08	10200.00	245.10	100000	4756863
3000000	7.50	2	0	2	1	19000.00	2500	4.17	6.00	2.50	1.50	4.00	4.08	10200.00	294.12	100000	5688235
3500000	7.50	2	0	2	1	19000.00	2500	4.17	6.00	2.50	1.50	4.00	4.08	10200.00	343.14	100000	6619608
4000000	7.50	2	0	2	1	19000.00	2500	4.17	6.00	2.50	1.50	4.00	4.08	10200.00	392.16	100000	7550980
4500000	7.50	2	0	2	1	19000.00	2500	4.17	6.00	2.50	1.50	4.00	4.08	10200.00	441.18	100000	8482353
5000000	7.50	2	0	2	1	19000.00	2500	4.17	6.00	2.50	1.50	4.00	4.08	10200.00	490.20	100000	9413725
5500000	7.50	2	0	2	1	19000.00	2500	4.17	6.00	2.50	1.50	4.00	4.08	10200.00	539.22	100000	10345098
6000000	7.50	2	0	2	1	19000.00	2500	4.17	6.00	2.50	1.50	4.00	4.08	10200.00	588.24	100000	11276471
6500000	7.50	2	0	2	1	19000.00	2500	4.17	6.00	2.50	1.50	4.00	4.08	10200.00	637.25	100000	12207843
7000000	7.50	2	0	2	1	19000.00	2500	4.17	6.00	2.50	1.50	4.00	4.08	10200.00	686.27	100000	13139216
7500000	7.50	2	0	2	1	19000.00	2500	4.17	6.00	2.50	1.50	4.00	4.08	10200.00	735.29	100000	14070588
8000000	7.50	2	0	2	1	19000.00	2500	4.17	6.00	2.50	1.50	4.00	4.08	10200.00	784.31	100000	15001961

* Assumes 17 hours per day operations and daily costs of: 1) Large Scow (2500 to 3000 cy) at $2,000/day; 2) Small Scow (1500 cy) at $800/day; 3) Large Tow at $6,000/day; and, 4) Small Tow at $3,000/day.

Table G33
Preliminary cost estimate to transport and dispose dredged sediments with a scow and tow from Upper Newport Bay to the White Point (Palos Verdes Shelf) aquatic capping site. Cost estimate matrix does not include dredging, mobilization/demobilization, supervision and administration, engineering and design, or contingency costs

SCOW AND TOW*
Orange County - Upper Newport Bay
to
Palos Verdes Shelf (White Point)

Dredge Volume (cy)	Distance to PV Shelf (nm)	No. of Large Scows	No. of Small Scows	No. of Large Tows	No. of Small Tows	Equip Cost Per Day ($)	Scow Capacity (cy)	No. of Hrs. To Capacity (hrs)	Avg Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (Trip) (hrs)	No. of Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Slurry Mod. Cost ($)	Total Cost Estimate ($)
1000000	29.00	4	0	3	2	32000.00	2500	4.17	6.00	9.67	1.50	11.17	4.08	10200.00	98.04	100000	3237255
1500000	29.00	4	0	3	2	32000.00	2500	4.17	6.00	9.67	1.50	11.17	4.08	10200.00	147.06	100000	4805882
2000000	29.00	4	0	3	2	32000.00	2500	4.17	6.00	9.67	1.50	11.17	4.08	10200.00	196.08	100000	6374510
2500000	29.00	4	0	3	2	32000.00	2500	4.17	6.00	9.67	1.50	11.17	4.08	10200.00	245.10	100000	7943137
3000000	29.00	4	0	3	2	32000.00	2500	4.17	6.00	9.67	1.50	11.17	4.08	10200.00	294.12	100000	9511765
3500000	29.00	4	0	3	2	32000.00	2500	4.17	6.00	9.67	1.50	11.17	4.08	10200.00	343.14	100000	11080392
4000000	29.00	4	0	3	2	32000.00	2500	4.17	6.00	9.67	1.50	11.17	4.08	10200.00	392.16	100000	12649020
4500000	29.00	4	0	3	2	32000.00	2500	4.17	6.00	9.67	1.50	11.17	4.08	10200.00	441.18	100000	14217647
5000000	29.00	4	0	3	2	32000.00	2500	4.17	6.00	9.67	1.50	11.17	4.08	10200.00	490.20	100000	15786275
5500000	29.00	4	0	3	2	32000.00	2500	4.17	6.00	9.67	1.50	11.17	4.08	10200.00	539.22	100000	17354902
6000000	29.00	4	0	3	2	32000.00	2500	4.17	6.00	9.67	1.50	11.17	4.08	10200.00	588.24	100000	18923529
6500000	29.00	4	0	3	2	32000.00	2500	4.17	6.00	9.67	1.50	11.17	4.08	10200.00	637.25	100000	20492157
7000000	29.00	4	0	3	2	32000.00	2500	4.17	6.00	9.67	1.50	11.17	4.08	10200.00	686.27	100000	22060784
7500000	29.00	4	0	3	2	32000.00	2500	4.17	6.00	9.67	1.50	11.17	4.08	10200.00	735.29	100000	23629412
8000000	29.00	4	0	3	2	32000.00	2500	4.17	6.00	9.67	1.50	11.17	4.08	10200.00	784.31	100000	25198039

* Assumes 17 hours per day operations and daily costs of: 1) Large Scow (2500 to 3000 cy) at $2,000/day; 2) Small Scow (1500 cy) at $800/day; 3) Large Tow at $6,000/day; and, 4) Small Tow at $3,000/day.

Table G34

Preliminary cost estimate to transport and dispose dredged sediments with a scow and tow from Portuguese Bend to the White Point (Palos Verdes Shelf) aquatic capping site. Cost estimate matrix does not include dredging, mobilization/demobilization, supervision and administration, engineering and design, or contingency costs

SCOW AND TOW*

Palos Verdes Peninsula - Portuguese Bend
to
Palos Verdes Shelf (White Point)

Dredge Volume (cy)	Distance to PV Shelf (nm)	No. of Large Scows	No. of Small Scows	No. of Large Tows	No. of Small Tows	Equip Cost Per Day ($)	Scow Capacity (cy)	No. of Hrs. To Capacity (hrs)	Avg Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (Trip) (hrs)	No. of Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Slurry Mod. Cost ($)	Total Cost Estimate ($)
1000000	3.50	0	2	1	2	13600.00	1500	2.50	7.00	1.00	1.50	2.50	6.80	10200.00	98.04	100000	1433333
1500000	3.50	0	2	1	2	13600.00	1500	2.50	7.00	1.00	1.50	2.50	6.80	10200.00	147.06	100000	2100000
2000000	3.50	0	2	1	2	13600.00	1500	2.50	7.00	1.00	1.50	2.50	6.80	10200.00	196.08	100000	2766667
2500000	3.50	0	2	1	2	13600.00	1500	2.50	7.00	1.00	1.50	2.50	6.80	10200.00	245.10	100000	3433333
3000000	3.50	0	2	1	2	13600.00	1500	2.50	7.00	1.00	1.50	2.50	6.80	10200.00	294.12	100000	4100000
3500000	3.50	0	2	1	2	13600.00	1500	2.50	7.00	1.00	1.50	2.50	6.80	10200.00	343.14	100000	4766667
4000000	3.50	0	2	1	2	13600.00	1500	2.50	7.00	1.00	1.50	2.50	6.80	10200.00	392.16	100000	5433333
4500000	3.50	0	2	1	2	13600.00	1500	2.50	7.00	1.00	1.50	2.50	6.80	10200.00	441.18	100000	6100000
5000000	3.50	0	2	1	2	13600.00	1500	2.50	7.00	1.00	1.50	2.50	6.80	10200.00	490.20	100000	6766667
5500000	3.50	0	2	1	2	13600.00	1500	2.50	7.00	1.00	1.50	2.50	6.80	10200.00	539.22	100000	7433333
6000000	3.50	0	2	1	2	13600.00	1500	2.50	7.00	1.00	1.50	2.50	6.80	10200.00	588.24	100000	8100000
6500000	3.50	0	2	1	2	13600.00	1500	2.50	7.00	1.00	1.50	2.50	6.80	10200.00	637.25	100000	8766667
7000000	3.50	0	2	1	2	13600.00	1500	2.50	7.00	1.00	1.50	2.50	6.80	10200.00	686.27	100000	9433333
7500000	3.50	0	2	1	2	13600.00	1500	2.50	7.00	1.00	1.50	2.50	6.80	10200.00	735.29	100000	10100000
8000000	3.50	0	2	1	2	13600.00	1500	2.50	7.00	1.00	1.50	2.50	6.80	10200.00	784.31	100000	10766667

* Assumes 17 hours per day operations and daily costs of: 1) Large Scow (2500 to 3000 cy) at $2,000/day; 2) Small Scow (1500 cy) at $800/day; 3) Large Tow at $6,000/day; and, 4) Small Tow at $3,000/day.

Table G35
Preliminary cost estimate to transport and dispose dredged sediments with a scow and tow from the Port of Los Angeles to the LA-2 Ocean Disposal Site. Cost estimate matrix does not include dredging, mobilization/demobilization, supervision and administration, engineering and design, or contingency costs

SCOW AND TOW*
Port of Los Angeles - Angel's Gate
to
LA-2 Ocean Disposal Site

Dredge Volume (cy)	Distance to LA-2 (nm)	No. of Large Scows	No. of Small Scows	No. of Large Tows	No. of Small Tows	Equip Cost Per Day ($)	Scow Capacity (cy)	No. of Hrs. To Capacity (hrs)	Avg Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (Trip) (hrs)	No. of Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Total Cost Estimate ($)
1000000	6.00	0	2	1	2	13600.00	1500.00	2.50	8.00	1.50	1.00	2.50	6.80	10200.00	98.04	1333333
1500000	6.00	0	2	1	2	13600.00	1500.00	2.50	8.00	1.50	1.00	2.50	6.80	10200.00	147.06	2000000
2000000	6.00	0	2	1	2	13600.00	1500.00	2.50	8.00	1.50	1.00	2.50	6.80	10200.00	196.08	2666667
2500000	6.00	0	2	1	2	13600.00	1500.00	2.50	8.00	1.50	1.00	2.50	6.80	10200.00	245.10	3333333
3000000	6.00	0	2	1	2	13600.00	1500.00	2.50	8.00	1.50	1.00	2.50	6.80	10200.00	294.12	4000000
3500000	6.00	0	2	1	2	13600.00	1500.00	2.50	8.00	1.50	1.00	2.50	6.80	10200.00	343.14	4666667
4000000	6.00	0	2	1	2	13600.00	1500.00	2.50	8.00	1.50	1.00	2.50	6.80	10200.00	392.16	5333333
4500000	6.00	0	2	1	2	13600.00	1500.00	2.50	8.00	1.50	1.00	2.50	6.80	10200.00	441.18	6000000
5000000	6.00	0	2	1	2	13600.00	1500.00	2.50	8.00	1.50	1.00	2.50	6.80	10200.00	490.20	6666667
5500000	6.00	0	2	1	2	13600.00	1500.00	2.50	8.00	1.50	1.00	2.50	6.80	10200.00	539.22	7333333
6000000	6.00	0	2	1	2	13600.00	1500.00	2.50	8.00	1.50	1.00	2.50	6.80	10200.00	588.24	8000000
6500000	6.00	0	2	1	2	13600.00	1500.00	2.50	8.00	1.50	1.00	2.50	6.80	10200.00	637.25	8666667
7000000	6.00	0	2	1	2	13600.00	1500.00	2.50	8.00	1.50	1.00	2.50	6.80	10200.00	686.27	9333333
7500000	6.00	0	2	1	2	13600.00	1500.00	2.50	8.00	1.50	1.00	2.50	6.80	10200.00	735.29	10000000
8000000	6.00	0	2	1	2	13600.00	1500.00	2.50	8.00	1.50	1.00	2.50	6.80	10200.00	784.31	10666667

* Assumes 17 hours per day operations and daily costs of: 1) Large Scow (2500 to 3000 cy) at $2,000/day; 2) Small Scow (1500 cy) at $800/day; 3) Large Tow at $6,000/day; and, 4) Small Tow at $3,000/day.

Table G36

Preliminary cost estimate to transport and dispose dredged sediments with a scow and tow from the Port of Long Beach to the LA-2 Ocean Disposal Site. Cost estimate matrix does not include dredging, mobilization/demobilization, supervision and administration, engineering and design, or contingency costs

SCOW AND TOW*
Port of Long Beach -Queen's Gate
to
LA-2 Ocean Disposal Site

Dredge Volume (cy)	Distance to LA-2 (nm)	No. of Large Scows	No. of Small Scows	No. of Large Tows	No. of Small Tows	Equip Cost Per Day ($)	Scow Capacity (cy)	No. of Hrs. To Capacity (hrs)	Avg Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (Trip) (hrs)	No. of Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Total Cost Estimate ($)
1000000	8.50	2	0	2	1	19000.00	2500.00	4.17	6.00	2.83	1.00	3.83	4.08	10200.00	98.04	1862745
1500000	8.50	2	0	2	1	19000.00	2500.00	4.17	6.00	2.83	1.00	3.83	4.08	10200.00	147.06	2794118
2000000	8.50	2	0	2	1	19000.00	2500.00	4.17	6.00	2.83	1.00	3.83	4.08	10200.00	196.08	3725490
2500000	8.50	2	0	2	1	19000.00	2500.00	4.17	6.00	2.83	1.00	3.83	4.08	10200.00	245.10	4656863
3000000	8.50	2	0	2	1	19000.00	2500.00	4.17	6.00	2.83	1.00	3.83	4.08	10200.00	294.12	5588235
3500000	8.50	2	0	2	1	19000.00	2500.00	4.17	6.00	2.83	1.00	3.83	4.08	10200.00	343.14	6519608
4000000	8.50	2	0	2	1	19000.00	2500.00	4.17	6.00	2.83	1.00	3.83	4.08	10200.00	392.16	7450980
4500000	8.50	2	0	2	1	19000.00	2500.00	4.17	6.00	2.83	1.00	3.83	4.08	10200.00	441.18	8382353
5000000	8.50	2	0	2	1	19000.00	2500.00	4.17	6.00	2.83	1.00	3.83	4.08	10200.00	490.20	9313725
5500000	8.50	2	0	2	1	19000.00	2500.00	4.17	6.00	2.83	1.00	3.83	4.08	10200.00	539.22	10245098
6000000	8.50	2	0	2	1	19000.00	2500.00	4.17	6.00	2.83	1.00	3.83	4.08	10200.00	588.24	11176471
6500000	8.50	2	0	2	1	19000.00	2500.00	4.17	6.00	2.83	1.00	3.83	4.08	10200.00	637.25	12107843
7000000	8.50	2	0	2	1	19000.00	2500.00	4.17	6.00	2.83	1.00	3.83	4.08	10200.00	686.27	13039216
7500000	8.50	2	0	2	1	19000.00	2500.00	4.17	6.00	2.83	1.00	3.83	4.08	10200.00	735.29	13970588
8000000	8.50	2	0	2	1	19000.00	2500.00	4.17	6.00	2.83	1.00	3.83	4.08	10200.00	784.31	14901961

* Assumes 17 hours per day operations and daily costs of: 1) Large Scow (2500 to 3000 cy) at $2,000/day; 2) Small Scow (1500 cy) at $800/day; 3) Large Tow at $6,000/day; and, 4) Small Tow at $3,000/day.

Table G37

Preliminary cost estimate to transport and dispose dredged sediments with a scow and tow from Upper Newport Bay to the LA-2 Ocean Disposal Site. Cost estimate matrix does not include dredging, mobilization/demobilization, supervision and administration, engineering and design, or contingency costs

SCOW AND TOW*
Orange County - Upper Newport Bay
to
LA-2 Ocean Disposal Site

Dredge Volume (cy)	Distance to LA-2 (nm)	No. of Large Scows	No. of Small Scows	No. of Large Tows	No. of Small Tows	Equip Cost Per Day ($)	Scow Capacity (cy)	No. of Hrs. To Capacity (hrs)	Avg Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (Trip) (hrs)	No. of Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Total Cost Estimate ($)
1000000	27.00	4	0	3	2	32000.00	2500.00	4.17	6.00	9.00	1.00	10.00	4.08	10200.00	98.04	3137255
1500000	27.00	4	0	3	2	32000.00	2500.00	4.17	6.00	9.00	1.00	10.00	4.08	10200.00	147.06	4705882
2000000	27.00	4	0	3	2	32000.00	2500.00	4.17	6.00	9.00	1.00	10.00	4.08	10200.00	196.08	6274510
2500000	27.00	4	0	3	2	32000.00	2500.00	4.17	6.00	9.00	1.00	10.00	4.08	10200.00	245.10	7843137
3000000	27.00	4	0	3	2	32000.00	2500.00	4.17	6.00	9.00	1.00	10.00	4.08	10200.00	294.12	9411765
3500000	27.00	4	0	3	2	32000.00	2500.00	4.17	6.00	9.00	1.00	10.00	4.08	10200.00	343.14	10980392
4000000	27.00	4	0	3	2	32000.00	2500.00	4.17	6.00	9.00	1.00	10.00	4.08	10200.00	392.16	12549020
4500000	27.00	4	0	3	2	32000.00	2500.00	4.17	6.00	9.00	1.00	10.00	4.08	10200.00	441.18	14117647
5000000	27.00	4	0	3	2	32000.00	2500.00	4.17	6.00	9.00	1.00	10.00	4.08	10200.00	490.20	15686275
5500000	27.00	4	0	3	2	32000.00	2500.00	4.17	6.00	9.00	1.00	10.00	4.08	10200.00	539.22	17254902
6000000	27.00	4	0	3	2	32000.00	2500.00	4.17	6.00	9.00	1.00	10.00	4.08	10200.00	588.24	18823529
6500000	27.00	4	0	3	2	32000.00	2500.00	4.17	6.00	9.00	1.00	10.00	4.08	10200.00	637.25	20392157
7000000	27.00	4	0	3	2	32000.00	2500.00	4.17	6.00	9.00	1.00	10.00	4.08	10200.00	686.27	21960784
7500000	27.00	4	0	3	2	32000.00	2500.00	4.17	6.00	9.00	1.00	10.00	4.08	10200.00	735.29	23529412
8000000	27.00	4	0	3	2	32000.00	2500.00	4.17	6.00	9.00	1.00	10.00	4.08	10200.00	784.31	25098039

* Assumes 17 hours per day operations and daily costs of: 1) Large Scow (2500 to 3000 cy) at $2,000/day; 2) Small Scow (1500 cy) at $800/day; 3) Large Tow at $6,000/day; and, 4) Small Tow at $3,000/day.

Table G38
Preliminary cost estimate to transport and dispose dredged sediments with a scow and tow from Portuguese Bend to the LA-2 Ocean Disposal site was not computed, since this scenario is considered not practical

SCOW AND TOW*
Palos Verdes Peninsula - Portuguese Bend
to
LA-2 Ocean Disposal Site

Dredge Volume (cy)	Distance to LA-2 (nm)	No. of Large Scows	No. of Small Scows	No. of Large Tows	No. of Small Tows	Equip Cost Per Day ($)	Scow Capacity (cy)	No. of Hrs. To Capacity (hrs)	Avg Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (Trip) (hrs)	No. of Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Total Cost Estimate ($)
NOT APPLICABLE																

* Assumes 17 hours per day operations and daily costs of: 1) Large Scow (2500 to 3000 cy) at $2,000/day; 2) Small Scow (1500 cy) at $800/day; 3) Large Tow at $6,000/day; and, 4) Small Tow at $3,000/day.

Table G39
Preliminary cost estimate to transport and dispose dredged sediments with a scow and tow from the Port of Los Angeles to the LA-3 Ocean Disposal site was not computed, since this scenario is considered not practical

SCOW AND TOW*
Port of Los Angeles - Angel's Gate
to
LA-3 Ocean Disposal Site

Dredge Volume (cy)	Distance to LA-3 (nm)	No. of Large Scows	No. of Small Scows	No. of Large Tows	No. of Small Tows	Equip Cost Per Day ($)	Scow Capacity (cy)	No. of Hrs. To Capacity (hrs)	Avg Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (Trip) (hrs)	No. of Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Total Cost Estimate ($)
NOT APPLICABLE																

* Assumes 17 hours per day operations and daily costs of: 1) Large Scow (2500 to 3000 cy) at $2,000/day; 2) Small Scow (1500 cy) at $800/day; 3) Large Tow at $6,000/day; and, 4) Small Tow at $3,000/day.

Table G40
Preliminary cost estimate to transport and dispose dredged sediments with a scow and tow from the Port of Long Beach to the LA-3 Ocean Disposal site was not computed, since this scenario is considered not practical

SCOW AND TOW*
Port of Long Beach - Queen's Gate
to
LA-3 Ocean Disposal Site

Dredge Volume (cy)	Distance to LA-3 (nm)	No. of Large Scows	No. of Small Scows	No. of Large Tows	No. of Small Tows	Equip Cost Per Day ($)	Scow Capacity (cy)	No. of Hrs. To Capacity (hrs)	Avg Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (Trip) (hrs)	No. of Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Total Cost Estimate ($)
NOT APPLICABLE																

* Assumes 17 hours per day operations and daily costs of: 1) Large Scow (2500 to 3000 cy) at $2,000/day; 2) Small Scow (1500 cy) at $800/day; 3) Large Tow at $6,000/day; and, 4) Small Tow at $3,000/day.

Table G41
Preliminary cost estimate to transport and dispose dredged sediments with a scow and tow from Upper Newport Bay to the LA-3 Ocean Disposal Site. Cost estimate matrix does not include dredging, mobilization/demobilization, supervision and administration, engineering and design, or contingency costs

SCOW AND TOW*
Orange County - Upper Newport Bay
to
LA-3 Ocean Disposal Site

Dredge Volume (cy)	Distance to LA-3 (nm)	No. of Large Scows	No. of Small Scows	No. of Large Tows	No. of Small Tows	Equip Cost Per Day ($)	Scow Capacity (cy)	No. of Hrs. To Capacity (hrs)	Avg Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (Trip) (hrs)	No. of Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Total Cost Estimate ($)
1000000	8.50	2	0	1	1	13000.00	2500.00	4.17	6.00	2.83	1.00	3.83	4.08	10200.00	98.04	1274510
1500000	8.50	2	0	1	1	13000.00	2500.00	4.17	6.00	2.83	1.00	3.83	4.08	10200.00	147.06	1911765
2000000	8.50	2	0	1	1	13000.00	2500.00	4.17	6.00	2.83	1.00	3.83	4.08	10200.00	196.08	2549020
2500000	8.50	2	0	1	1	13000.00	2500.00	4.17	6.00	2.83	1.00	3.83	4.08	10200.00	245.10	3186275
3000000	8.50	2	0	1	1	13000.00	2500.00	4.17	6.00	2.83	1.00	3.83	4.08	10200.00	294.12	3823529
3500000	8.50	2	0	1	1	13000.00	2500.00	4.17	6.00	2.83	1.00	3.83	4.08	10200.00	343.14	4460784
4000000	8.50	2	0	1	1	13000.00	2500.00	4.17	6.00	2.83	1.00	3.83	4.08	10200.00	392.16	5098039
4500000	8.50	2	0	1	1	13000.00	2500.00	4.17	6.00	2.83	1.00	3.83	4.08	10200.00	441.18	5735294
5000000	8.50	2	0	1	1	13000.00	2500.00	4.17	6.00	2.83	1.00	3.83	4.08	10200.00	490.20	6372549
5500000	8.50	2	0	1	1	13000.00	2500.00	4.17	6.00	2.83	1.00	3.83	4.08	10200.00	539.22	7009804
6000000	8.50	2	0	1	1	13000.00	2500.00	4.17	6.00	2.83	1.00	3.83	4.08	10200.00	588.24	7647059
6500000	8.50	2	0	1	1	13000.00	2500.00	4.17	6.00	2.83	1.00	3.83	4.08	10200.00	637.25	8284314
7000000	8.50	2	0	1	1	13000.00	2500.00	4.17	6.00	2.83	1.00	3.83	4.08	10200.00	686.27	8921569
7500000	8.50	2	0	1	1	13000.00	2500.00	4.17	6.00	2.83	1.00	3.83	4.08	10200.00	735.29	9558824
8000000	8.50	2	0	1	1	13000.00	2500.00	4.17	6.00	2.83	1.00	3.83	4.08	10200.00	784.31	10196078

* Assumes 17 hours per day operations and daily costs of: 1) Large Scow (2500 to 3000 cy) at $2,000/day; 2) Small Scow (1500 cy) at $800/day; 3) Large Tow at $6,000/day; and, 4) Small Tow at $3,000/day.

Table G42
Preliminary cost estimate to transport and dispose dredged sediments with a scow and tow from Portuguese Bend to the LA-3 Ocean Disposal site was not computed, since this scenario is considered not practical

SCOW AND TOW*
Palos Verdes Peninsula - Portuguese Bend
to
LA-3 Ocean Disposal Site

Dredge Volume (cy)	Distance to LA-3 (nm)	No. of Large Scows	No. of Small Scows	No. of Large Tows	No. of Small Tows	Equip Cost Per Day ($)	Scow Capacity (cy)	No. of Hrs. To Capacity (hrs)	Avg Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (Trip) (hrs)	No. of Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Total Cost Estimate ($)
NOT APPLICABLE																

* Assumes 17 hours per day operations and daily costs of: 1) Large Scow (2500 to 3000 cy) at $2,000/day; 2) Small Scow (1500 cy) at $800/day; 3) Large Tow at $6,000/day; and, 4) Small Tow at $3,000/day.

Table G43

Preliminary cost estimate to transport and dispose dredged sediments with a scow and tow from the Port of Los Angeles to an In-Harbor aquatic disposal site (Cabrillo Shallow Water Habitat Confined Aquatic Disposal Site). Cost estimate matrix does not include dredging, mobilization/demobilization, supervision and administration, engineering and design, or contingency costs

SCOW AND TOW*
Port of Los Angeles - Angel's Gate
to
In-Harbor (POLA) Aquatic Disposal

Dredge Volume (cy)	Distance to In-Harbor (nm)	No. of Large Scows	No. of Small Scows	No. of Large Tows	No. of Small Tows	Equip Cost Per Day ($)	Scow Capacity (cy)	No. of Hrs. To Capacity (hrs)	Avg Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (Trip) (hrs)	No. of Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Total Cost Estimate ($)
1000000	0.50	0	2	0	1	4600.00	1500.00	2.50	3.00	0.33	0.25	0.58	6.80	10200.00	98.04	450980
1500000	0.50	0	2	0	1	4600.00	1500.00	2.50	3.00	0.33	0.25	0.58	6.80	10200.00	147.06	676471
2000000	0.50	0	2	0	1	4600.00	1500.00	2.50	3.00	0.33	0.25	0.58	6.80	10200.00	196.08	901961
2500000	0.50	0	2	0	1	4600.00	1500.00	2.50	3.00	0.33	0.25	0.58	6.80	10200.00	245.10	1127451
3000000	0.50	0	2	0	1	4600.00	1500.00	2.50	3.00	0.33	0.25	0.58	6.80	10200.00	294.12	1352941
3500000	0.50	0	2	0	1	4600.00	1500.00	2.50	3.00	0.33	0.25	0.58	6.80	10200.00	343.14	1578431
4000000	0.50	0	2	0	1	4600.00	1500.00	2.50	3.00	0.33	0.25	0.58	6.80	10200.00	392.16	1803922
4500000	0.50	0	2	0	1	4600.00	1500.00	2.50	3.00	0.33	0.25	0.58	6.80	10200.00	441.18	2029412
5000000	0.50	0	2	0	1	4600.00	1500.00	2.50	3.00	0.33	0.25	0.58	6.80	10200.00	490.20	2254902
5500000	0.50	0	2	0	1	4600.00	1500.00	2.50	3.00	0.33	0.25	0.58	6.80	10200.00	539.22	2480392
6000000	0.50	0	2	0	1	4600.00	1500.00	2.50	3.00	0.33	0.25	0.58	6.80	10200.00	588.24	2705882
6500000	0.50	0	2	0	1	4600.00	1500.00	2.50	3.00	0.33	0.25	0.58	6.80	10200.00	637.25	2931373
7000000	0.50	0	2	0	1	4600.00	1500.00	2.50	3.00	0.33	0.25	0.58	6.80	10200.00	686.27	3156863
7500000	0.50	0	2	0	1	4600.00	1500.00	2.50	3.00	0.33	0.25	0.58	6.80	10200.00	735.29	3382353
8000000	0.50	0	2	0	1	4600.00	1500.00	2.50	3.00	0.33	0.25	0.58	6.80	10200.00	784.31	3607843

* Assumes 17 hours per day operations and daily costs of: 1) Large Scow (2500 to 3000 cy) at $2,000/day; 2) Small Scow (1500 cy) at $800/day; 3) Large Tow at $6,000/day; and, 4) Small Tow at $3,000/day.

Table G44
Preliminary cost estimate to transport and dispose dredged sediments with a scow and tow from the Port of Long Beach to an In-Harbor aquatic disposal site (Energy Island Borrow Pits). Cost estimate matrix does not include dredging, mobilization/demobilization, supervision and administration, engineering and design, or contingency costs

SCOW AND TOW*
Port of Long Beach - Queen's Gate
to
In-Harbor (POLB) Aquatic Disposal

Dredge Volume (cy)	Distance to In-Harbor (nm)	No. of Large Scows	No. of Small Scows	No. of Large Tows	No. of Small Tows	Equip Cost Per Day ($)	Scow Capacity (cy)	No. of Hrs. To Capacity (hrs)	Avg Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (Trip) (hrs)	No. of Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Total Cost Estimate ($)
1000000	2.00	0	2	0	2	7600.00	1500.00	2.50	3.00	1.33	0.25	1.58	6.80	10200.00	98.04	745098
1500000	2.00	0	2	0	2	7600.00	1500.00	2.50	3.00	1.33	0.25	1.58	6.80	10200.00	147.06	1117647
2000000	2.00	0	2	0	2	7600.00	1500.00	2.50	3.00	1.33	0.25	1.58	6.80	10200.00	196.08	1490196
2500000	2.00	0	2	0	2	7600.00	1500.00	2.50	3.00	1.33	0.25	1.58	6.80	10200.00	245.10	1862745
3000000	2.00	0	2	0	2	7600.00	1500.00	2.50	3.00	1.33	0.25	1.58	6.80	10200.00	294.12	2235294
3500000	2.00	0	2	0	2	7600.00	1500.00	2.50	3.00	1.33	0.25	1.58	6.80	10200.00	343.14	2607843
4000000	2.00	0	2	0	2	7600.00	1500.00	2.50	3.00	1.33	0.25	1.58	6.80	10200.00	392.16	2980392
4500000	2.00	0	2	0	2	7600.00	1500.00	2.50	3.00	1.33	0.25	1.58	6.80	10200.00	441.18	3352941
5000000	2.00	0	2	0	2	7600.00	1500.00	2.50	3.00	1.33	0.25	1.58	6.80	10200.00	490.20	3725490
5500000	2.00	0	2	0	2	7600.00	1500.00	2.50	3.00	1.33	0.25	1.58	6.80	10200.00	539.22	4098039
6000000	2.00	0	2	0	2	7600.00	1500.00	2.50	3.00	1.33	0.25	1.58	6.80	10200.00	588.24	4470588
6500000	2.00	0	2	0	2	7600.00	1500.00	2.50	3.00	1.33	0.25	1.58	6.80	10200.00	637.25	4843137
7000000	2.00	0	2	0	2	7600.00	1500.00	2.50	3.00	1.33	0.25	1.58	6.80	10200.00	686.27	5215686
7500000	2.00	0	2	0	2	7600.00	1500.00	2.50	3.00	1.33	0.25	1.58	6.80	10200.00	735.29	5588235
8000000	2.00	0	2	0	2	7600.00	1500.00	2.50	3.00	1.33	0.25	1.58	6.80	10200.00	784.31	5960784

* Assumes 17 hours per day operations and daily costs of: 1) Large Scow (2500 to 3000 cy) at $2,000/day; 2) Small Scow (1500 cy) at $800/day; 3) Large Tow at $6,000/day; and, 4) Small Tow at $3,000/day.

Table G45
Preliminary cost estimate to transport and dispose dredged sediments with a scow and tow from Upper Newport Bay to an In-Harbor aquatic disposal site was not computed, since this scenario is considered not practical

SCOW AND TOW*
Orange County - Upper Newport Bay
to
In-Harbor Aquatic Disposal

Dredge Volume (cy)	Distance to In-Harbor (nm)	No. of Large Scows	No. of Small Scows	No. of Large Tows	No. of Small Tows	Equip Cost Per Day ($)	Scow Capacity (cy)	No. of Hrs. To Capacity (hrs)	Avg Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (Trip) (hrs)	No. of Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Total Cost Estimate ($)
NOT APPLICABLE																

* Assumes 17 hours per day operations and daily costs of: 1) Large Scow (2500 to 3000 cy) at $2,000/day; 2) Small Scow (1500 cy) at $800/day; 3) Large Tow at $6,000/day; and, 4) Small Tow at $3,000/day.

Table G46
Preliminary cost estimate to transport and dispose dredged sediments with a scow and tow from Portuguese Bend to an In-Harbor aquatic disposal site was not computed, since this scenario is considered not practical

SCOW AND TOW*
Palos Verdes Peninsula - Portuguese Bend
to
In-Harbor Aquatic Disposal

Dredge Volume (cy)	Distance to In-Harbor (nm)	No. of Large Scows	No. of Small Scows	No. of Large Tows	No. of Small Tows	Equip Cost Per Day ($)	Scow Capacity (cy)	No. of Hrs. To Capacity (hrs)	Avg Speed (kts)	Round Trip Hrs. to Site (hrs)	No. of Hrs. on Station (hrs)	Tot. Cycle Time (Trip) (hrs)	No. of Loads Per Day	Production Rate/Day (cy)	Tot. Days of Ops (days)	Total Cost Estimate ($)
NOT APPLICABLE																

* Assumes 17 hours per day operations and daily costs of: 1) Large Scow (2500 to 3000 cy) at $2,000/day; 2) Small Scow (1500 cy) at $800/day; 3) Large Tow at $6,000/day; and, 4) Small Tow at $3,000/day.

Table G47
Disposal cost comparisons for dredged sediments originating from the Port of Los Angeles and transported and aquatically disposed via scow and tow. Values given in dollars and does not include mob/demob costs

SCOW AND TOW
Port of Los Angeles - Angel's Gate
Disposal Site Cost Comparison

Dredge Volume (cy)		PV Shelf Est. Cost ($)	LA-2 Est. Cost ($)	LA-3 Est. Cost ($)	In-Harbor Est. Cost ($)		CLAMSHELL PV Shelf vs. LA-2 (Delta $)	CLAMSHELL PV Shelf vs. LA-3 (Delta $)	CLAMSHELL PV Shelf vs. In-Harbor (Delta $)	HYDRAULIC PV Shelf vs. In-Harbor (Delta $)
1000000		1500000	1333333	n/a	450980		166667	n/a	1049020	1500000
1500000		2200000	2000000	n/a	676471		200000	n/a	1523529	2200000
2000000		2900000	2666667	n/a	901961		233333	n/a	1998039	2900000
2500000		3600000	3333333	n/a	1127451		266667	n/a	2472549	3600000
3000000		4300000	4000000	n/a	1352941		300000	n/a	2947059	4300000
3500000		5000000	4666667	n/a	1578431		333333	n/a	3421569	5000000
4000000		5700000	5333333	n/a	1803922		366667	n/a	3896078	5700000
4500000		6400000	6000000	n/a	2029412		400000	n/a	4370588	6400000
5000000		7100000	6666667	n/a	2254902		433333	n/a	4845098	7100000
5500000		7800000	7333333	n/a	2480392		466667	n/a	5319608	7800000
6000000		8500000	8000000	n/a	2705882		500000	n/a	5794118	8500000
6500000		9200000	8666667	n/a	2931373		533333	n/a	6268627	9200000
7000000		9900000	9333333	n/a	3156863		566667	n/a	6743137	9900000
7500000		10600000	10000000	n/a	3382353		600000	n/a	7217647	10600000
8000000		11300000	10666667	n/a	3607843		633333	n/a	7692157	11300000

Table G48
Disposal cost comparisons for dredged sediments originating from the Port of Long Beach and transported and aquatically disposed via scow and tow. Values given in dollars and does not include mob/demob costs

SCOW AND TOW
Port of Long Beach - Queen's Gate
Disposal Site Cost Comparison

Dredge Volume (cy)		PV Shelf Est. Cost ($)	LA-2 Est. Cost ($)	LA-3 Est. Cost ($)	In-Harbor Est. Cost ($)		CLAMSHELL PV Shelf vs. LA-2 (Delta $)	CLAMSHELL PV Shelf vs. LA-3 (Delta $)	CLAMSHELL PV Shelf vs. In-Harbor (Delta $)	HYDRAULIC PV Shelf vs. In-Harbor (Delta $)
1000000		1962745	1862745	n/a	745098		100000	n/a	1217647	1962745
1500000		2894118	2794118	n/a	1117647		100000	n/a	1776471	2894118
2000000		3825490	3725490	n/a	1490196		100000	n/a	2335294	3825490
2500000		4756863	4656863	n/a	1862745		100000	n/a	2894118	4756863
3000000		5688235	5588235	n/a	2235294		100000	n/a	3452941	5688235
3500000		6619608	6519608	n/a	2607843		100000	n/a	4011765	6619608
4000000		7550980	7450980	n/a	2980392		100000	n/a	4570588	7550980
4500000		8482353	8382353	n/a	3352941		100000	n/a	5129412	8482353
5000000		9413725	9313725	n/a	3725490		100000	n/a	5688235	9413725
5500000		10345098	10245098	n/a	4098039		100000	n/a	6247059	10345098
6000000		11276471	11176471	n/a	4470588		100000	n/a	6805882	11276471
6500000		12207843	12107843	n/a	4843137		100000	n/a	7364706	12207843
7000000		13139216	13039216	n/a	5215686		100000	n/a	7923529	13139216
7500000		14070588	13970588	n/a	5588235		100000	n/a	8482353	14070588
8000000		15001961	14901961	n/a	5960784		100000	n/a	9041176	15001961

Table G49
Disposal cost comparisons for dredged sediments originating from Upper Newport Bay and transported and aquatically disposed via scow and tow. Values given in dollars and does not include mob/demob costs

SCOW AND TOW
Orange County - Upper Newport Bay
Disposal Site Cost Comparison

Dredge Volume (cy)		PV Shelf Est. Cost ($)	LA-2 Est. Cost ($)	LA-3 Est. Cost ($)	In-Harbor Est. Cost ($)		CLAMSHELL PV Shelf vs. LA-2 (Delta $)	CLAMSHELL PV Shelf vs. LA-3 (Delta $)	CLAMSHELL PV Shelf vs. In-Harbor (Delta $)	HYDRAULIC PV Shelf vs. In-Harbor (Delta $)
1000000		3237255	3137255	1274510	n/a		100000	1962745	n/a	n/a
1500000		4805882	4705882	1911765	n/a		100000	2894118	n/a	n/a
2000000		6374510	6274510	2549020	n/a		100000	3825490	n/a	n/a
2500000		7943137	7843137	3186275	n/a		100000	4756863	n/a	n/a
3000000		9511765	9411765	3823529	n/a		100000	5688235	n/a	n/a
3500000		11080392	10980392	4460784	n/a		100000	6619608	n/a	n/a
4000000		12649020	12549020	5098039	n/a		100000	7550980	n/a	n/a
4500000		14217647	14117647	5735294	n/a		100000	8482353	n/a	n/a
5000000		15786275	15686275	6372549	n/a		100000	9413725	n/a	n/a
5500000		17354902	17254902	7009804	n/a		100000	10345098	n/a	n/a
6000000		18923529	18823529	7647059	n/a		100000	11276471	n/a	n/a
6500000		20492157	20392157	8284314	n/a		100000	12207843	n/a	n/a
7000000		22060784	21960784	8921569	n/a		100000	13139216	n/a	n/a
7500000		23629412	23529412	9558824	n/a		100000	14070588	n/a	n/a
8000000		25198039	25098039	10196078	n/a		100000	15001961	n/a	n/a

Table G50
Disposal cost comparisons for dredged sediments originating from Portuguese Bend and transported and aquatically disposed via scow and tow. Values given in dollars and includes the cost to mechanically dredge sediments from behind the proposed containment dike

SCOW AND TOW
Palos Verdes Peninsula - Portuguese Bend
Disposal Site Cost Comparison

Dredge Volume (cy)	PV Shelf Est. Cost ($)	LA-2 Est. Cost ($)	LA-3 Est. Cost ($)	In-Harbor Est. Cost ($)	CLAMSHELL PV Shelf vs. LA-2 (Delta $)	CLAMSHELL PV Shelf vs. LA-3 (Delta $)	CLAMSHELL PV Shelf vs. In-Harbor (Delta $)	HYDRAULIC PV Shelf vs. In-Harbor (Delta $)	Containment Dike Dredge Cost ($)	Dredging & Transport Cost ($)
1000000	1433333	n/a	n/a	n/a	n/a	n/a	n/a	n/a	4000000	5433333
1500000	2100000	n/a	n/a	n/a	n/a	n/a	n/a	n/a	5500000	7600000
2000000	2766667	n/a	n/a	n/a	n/a	n/a	n/a	n/a	7000000	9766667
2500000	3433333	n/a	n/a	n/a	n/a	n/a	n/a	n/a	8500000	11933333
3000000	4100000	n/a	n/a	n/a	n/a	n/a	n/a	n/a	10000000	14100000
3500000	4766667	n/a	n/a	n/a	n/a	n/a	n/a	n/a	11500000	16266667
4000000	5433333	n/a	n/a	n/a	n/a	n/a	n/a	n/a	13000000	18433333
4500000	6100000	n/a	n/a	n/a	n/a	n/a	n/a	n/a	14500000	20600000
5000000	6766667	n/a	n/a	n/a	n/a	n/a	n/a	n/a	16000000	22766667
5500000	7433333	n/a	n/a	n/a	n/a	n/a	n/a	n/a	17500000	24933333
6000000	8100000	n/a	n/a	n/a	n/a	n/a	n/a	n/a	19000000	27100000
6500000	8766667	n/a	n/a	n/a	n/a	n/a	n/a	n/a	20500000	29266667
7000000	9433333	n/a	n/a	n/a	n/a	n/a	n/a	n/a	22000000	31433333
7500000	10100000	n/a	n/a	n/a	n/a	n/a	n/a	n/a	23500000	33600000
8000000	10766667	n/a	n/a	n/a	n/a	n/a	n/a	n/a	25000000	35766667

Appendix H - Sediment Profile Data

This appendix presents sediment data for stations sampled by the USGS (Lee 1994) using a box core. Core samples were tested for total DDT, DDE, PCBs, and total organic carbon (TOC) content using 2-cm or 4-cm core increments. Table H1 summarizes the properties of the EA sediment layers for each station. For this study, individual 2-cm increments from the USGS cores were grouped into layers defined based on logical breaks or changes in sediment density, TOC, PCB, or total DDT as indicated in Table H1.

Table H1
Summary of USGS sediment data by core station

Station	Core No.	Increment (cm)	Dry density (g/cc)	Dry ave. density (g/cc)	Total PCB (ppm)	Total DDT (ppm)	p,p-DDE (ppm)	TOC (%)
500	101-B5	0-2	1.31		0.009	0.015	0.009	0.50
		2-4	1.32		NR	0.016	0.009	0.51
		4-6	1.36		0.009	0.023	0.014	0.51
		6-8	1.38	1.342	0.010	0.028	0.017	0.51
500	187-B1	0-2	1.32		NR	0.014	0.008	0.44
		2-4	1.37		NR	0.016	0.010	0.50
		4-6	1.40		NR	0.017	0.011	0.73
		6-8	1.42	1.377	NR	0.018	0.011	0.40
506	163-B1	0-4	0.67		0.125	1.060	0.876	2.02
		4-8	0.78	0.725	0.169	1.410	1.150	2.27
514	160-B1	0-4	0.97		0.356	4.050	3.200	1.17
		4-8	0.96		0.350	4.420	3.500	1.38
		8-12	1.00		0.381	4.410	3.430	1.44
		12-16	0.99	0.980	0.489	5.060	3.890	1.50
		16-20	0.93		0.780	14.600	10.800	2.01
		20-24	0.95	0.940	0.691	16.100	12.100	1.83
		24-28	1.16		0.427	8.940	6.990	1.30
		28-32	1.32	1.240	0.277	3.850	2.760	0.92
		32-36	0.47	0.470	0.115	1.530	1.150	0.71
516	166-B1	0-4	0.99	0.990	0.102	1.230	1.040	2.03
		4-8	1.19	1.190	0.039	0.428	0.350	1.97
		8-12	1.21	1.210	NR	NR	0.002	1.98
518	106-B1	0-4	0.20		0.331	2.770	2.060	1.40
		4-8	1.22	0.710	0.336	2.260	1.810	0.68
		8-12	1.32	1.320	0.851	6.070	4.560	0.51
519	159-B1	0-4	0.75	0.750	2.790	3.040	2.270	2.05
		4-8	0.81	0.810	0.490	3.830	2.520	2.28
		8-12	1.02		0.249	2.150	1.510	1.52
		12-16	1.05	1.035	0.246	2.630	1.760	1.40

Station	Core No.	Increment (cm)	Dry density g/cc	Dry ave. density g/cc	Total PCB (ppm)	Total DDT (ppm)	p,p'-DDE (ppm)	TOC (%)
522	109-W1	0-2	0.86		0.409	3.650	2.580	1.71
		2-4	0.94		0.410	3.81	2.700	1.45
		4-6	0.95		0.478	4.100	2.980	1.58
		6-8	0.98		0.515	3.930	2.840	1.28
		8-10	1.02		0.494	4.020	3.000	1.60
		10-12	1.02		0.451	3.750	2.770	1.72
		12-14	0.96		0.479	4.190	3.110	1.88
		14-16	0.98		0.501	4.140	3.040	1.60
		16-18	1.01		0.533	4.220	3.090	1.83
		18-20	0.98		0.659	4.530	3.130	1.85
		20-22	0.98		0.575	4.280	2.910	1.82
		22-24	0.98	0.972	0.532	4.050	2.970	1.87
522	109-W2	0-2	0.89		0.375	3.140	2.220	1.32
		2-4	0.93		0.372	2.960	2.090	1.30
		4-6	0.96		0.470	3.780	2.780	1.48
		6-8	1.04		0.495	3.980	2.960	1.60
		8-10	1.02		0.437	3.630	2.620	1.46
		10-12	0.93		0.447	3.640	2.600	1.62
		12-14	0.93		0.486	4.200	3.070	1.99
		14-16	0.99		0.441	3.860	2.870	1.71
		16-18	1.02		0.438	3.770	2.790	1.85
		18-20	1.02	0.973	0.329	2.930	2.130	1.59
522	123-W2	0-2	0.84		0.406	3.650	2.610	1.50
		2-4	0.94		0.333	2.920	2.090	1.32
		4-6	0.97		0.374	3.190	2.280	1.22
		6-8	0.94	0.922	0.268	2.000	1.460	1.43
		8-10	0.97		0.493	4.180	3.030	1.47
		10-12	0.98		0.508	4.390	3.240	1.60
		12-14	0.97		0.505	4.560	3.350	1.51
		14-16	0.94		0.425	4.070	3.040	1.68
		16-18	0.97		0.396	3.590	2.710	1.64
		18-20	0.93		0.438	3.630	2.730	1.89
		20-22	0.91	0.953	0.533	4.390	3.190	2.06
		22-24	0.87		0.749	6.560	4.18	236
		24-26	0.87		0.841	6.910	4.560	2.47
		26-28	0.89		0.724	6.180	4.300	2.65
		28-30	0.80	0.857	0.797	6.560	4.660	2.44

Station	Core No.	Increment (cm)	Dry density (g/cc)	Dry ave. density (g/cc)	Total PCB (ppm)	Total DDT (ppm)	p,p-DDE (ppm)	TOC (%)
522	124-B1	0-2	0.81		0.563	4.930	3.460	2.13
		2-4	0.95		0.497	4.690	3.370	1.29
		4-6	0.99		0.443	4.020	2.940	1.34
		6-8	0.97		0.561	3.420	2.330	1.39
		8-10	1.00		0.732	5.500	3.720	1.52
		10-12	1.03		0.582	4.390	2.930	1.51
		12-14	1.05		0.560	4.070	2.770	1.28
		14-16	0.90		0.577	4.370	2.860	1.35
		16-18	0.89		0.434	2.790	1.970	1.67
		18-20	0.93		0.212	2.450	1.75	1.51
		20-22	0.99		0.388	4.070	2.770	1.68
		22-24	0.91		0.488	5.150	3.640	1.63
		24-26	0.91		0.692	6.230	4.460	1.94
		26-28	0.78		0.728	6.690	4.270	2.35
		28-30	0.80	0.927	1.230	8.850	6.230	1.16
		30-32	1.00		2.740	22.300	13.000	2.87
		32-34	1.08		1.820	18.200	11.000	2.48
		34-36	1.03		1.020	11.900	9.220	1.62
		36-38	1.11	1.055	1.080	17.400	14.000	1.74
		38-40	1.26		1.100	8.790	6.300	1.66
		40-42	1.29		0.426	3.260	1.980	1.05
		42-44	1.25		0.174	1.700	0.928	0.98
		44-46	1.36		0.175	1.490	0.876	1.21
		46-48	1.28	1.288	0.193	1.270	0.824	0.86
523	108-B2	0-2	0.71		0.444	4.850	3.800	2.26
		2-4	0.74		0.484	4.000	2.870	2.29
		4-6	0.82	0.757	0.590	5.690	4.430	2.66
		6-8	0.97		0.773	7.66	5.65	2.72
		8-10	1.13		1.300	9.870	6.530	2.51
		10-12	1.27	1.123	0.921	5.800	3.640	2.02
		12-14	1.35		0.435	4.130	1.800	1.16
		14-16	1.39		0.199	1.840	1.160	1.13
		16-18	1.39	1.377	0.100	0.585	0.303	0.81

Station	Core No.	Increment (cm)	Dry density (g/cc)	Dry ave. density (g/cc)	Total PCB (ppm)	Total DDT (ppm)	p,p-DDE (ppm)	TOC (%)
524	102-B1	0-2	0.74		0.433	4.080	3.180	2.5
		2-4	0.97		0.624	5.940	4.460	3.10
		4-6	1.09		0.523	3.700	2.410	1.46
		6-8	1.14	0.985	0.380	4.390	3.260	1.35
		8-10	1.14		0.192	1.710	1.060	1.12
		10-12	1.16		0.122	0.797	0.422	1.13
		12-14	1.19		0.125	0.816	0.406	1.12
		14-16	1.23	1.180	0.072	0.977	0.586	1.06
525	156-B1	0-2	0.53		0.108	0.785	0.547	1.08
		2-4	0.56	0.545	0.180	1.550	1.060	2.49
532	148-B1	0-4	0.63		0.702	6.660	4.300	2.71
		4-8	0.67		0.879	7.480	5.510	2.76
		8-12	0.63		1.020	8.870	6.950	3.05
		12-16	0.66	0.647	0.960	8.100	5.950	3.50
		16-20	0.64		3.130	24.300	13.000	4.69
		20-24	0.98	0.810	2.720	31.400	18.4	3.84
		24-28	1.26		0.651	8.260	5.62	1.69
		28-32	1.32	1.290	0.141	1.060	0.585	1.05
533	149-B1	0-4	0.61		0.93	7.660	5.890	3.03
		4-8	0.59		1.080	6.900	5.060	3.10
		8-12	0.58		2.440	11.200	7.970	4.44
		12-16	0.58	0.590	0.960	8.16	6.350	4.57
		16-20	0.60		4.310	25.500	14.300	5.06
		20-24	0.83	0.715	1.280	10.100	6.590	2.89
		24-28	1.20		0.292	1.730	1.130	1.42
		28-32	1.27		0.016	0.160	0.077	0.94
		32-36	1.26	1.243	0.014	0.114	0.089	84
534	173-B1	0-4	1.01		0.246	1.590	1.070	0.87
		4-8	1.03		0.308	2.170	1.470	1.04
		8-12	1.08		0.323	2.250	1.530	0.93
		12-16	1.04		0.184	1.590	1.020	1.02
		16-20	1.02		0.232	1.360	0.770	1.14
		20-24	0.98		0.326	2.680	1.790	1.19
		24-28	1.00		0.492	3.630	2.500	1.29
		28-32	0.98		0.436	3.490	2.310	1.44
		32-36	0.99		0.322	2.350	1.530	1.38
		36-40	0.98		0.414	2.660	1.650	1.70
		40-44	1.04		0.818	6.120	3.470	1.68
		44-48	1.15		0.435	3.590	2.180	1.39
		48-52	1.11	1.032	0.122	0.917	0.513	1.39

Station	Core No.	Increment (cm)	Dry density (g/cc)	Dry ave. density (g/cc)	Total PCB (ppm)	Total DDT (ppm)	p,p-DDE (ppm)	TOC (%)
536	174-B1	0-4	0.73		0.511	5.150	3.800	1.93
		4-8	0.78		0.586	5.540	4.170	1.93
		8-12	0.81		0.943	8.510	5.890	2.45
		12-16	0.84		0.300	3.040	2.340	2.44
		16-20	0.68	0.768	1.440	11.700	7.710	2.93
		20-24	0.54		2.460	24.400	16.100	3.87
		24-28	0.56		4.970	65.400	41.600	5.36
		28-32	0.63		1.050	10.300	7.370	3.63
		32-36	0.99	0.680	5.040	50.100	32.600	5.89
		36-40	1.34		0.466	4.160	2.840	1.49
		40-44	1.39	1.365	0.055	0.628	0.432	0.76
539	111 -B1	0 - 4	0.86		0.419	4.060	2.600	1.29
		4-8	0.93		0.346	3.170	2.010	1.26
		8-12	0.97		0.355	3.120	2.060	1.18
		12-16	0.99		0.323	2.340	1.440	1.10
		16-20	0.87		0.367	3.600	2.330	1.31
		20-24	0.94		0.510	4.230	2.720	1.44
		24-28	0.95		0.492	4.100	2.640	1.29
		28-32	0.89		0.484	3.600	2.360	1.52
		32-36	0.92		0.553	4.820	3.070	1.53
		36-40	0.91		0.530	4.550	2.960	1.53
		40-44	0.85		0.511	4.610	2.610	1.50
		44-48	0.84		0.283	1.940	1.180	1.96
		48-52	0.88	0.908	0.828	5.590	3.660	2.20
		52-56	0.92		2.270	16.000	9.800	2.26
		56-60	0.86	0.890	2.070	16.200	9.160	2.22
542	113-B1	0-4	0.92		0.163	1.880	1.210	1.54
		4-8	1.09	1.005	0.090	1.100	0.581	1.16
		8-12	1.17		0.043	0.377	0.221	1.11
		12-16	1.21		0.019	0.167	0.104	0.85
		16-20	1.28	1.220	NR	NR	NR	0.83
543	114-B1	0-4	0.67	0.670	0.189	1.760	1.350	1.99
		4-8	0.88		0.067	0.642	0.479	1.34
		8-12	0.91		0.028	0.199	0.132	1.25
		12-16	0.88	0.890	0.023	0.206	0	1.25
544	115-B2	0-4	0.50		0.335	3.870	3.140	2.71
		4-8	0.61		0.503	9.800	8.150	2.63
		0-8		0.555		7.122	5.887	

Station	Core No.	Increment (cm)	Dry density (g/cc)	Dry ave. density (g/cc)	Total PCB (ppm)	Total DDT (ppm)	p,p-DDE (ppm)	TOC (%)
547	143-B1	0-4	1.25		0.070	0.487	0.319	0.43
		4-8	1.31		0.110	0.823	0.530	1.58
		8-12	1.33		0.094	0.609	0.396	0.82
		12-16	1.33	1.305	0.031	0.210	0.130	0.31
		16-20	1.43		0.085	0.549	0.337	0.16
		20-24	1.54		0.090	0.647	0.348	0.86
		24-28	1.49		0.082	0.565	0.317	1.04
		28-32	1.51	1.492	0.045	0.266	0.154	0.57
550	169-B1	0-2	0.59		0.987	12.900	8.310	2.53
		2-4	0.64		0.776	9.580	6.800	2.42
		4-6	0.69		0.929	10.000	3.700	2.67
		6-8	0.70		0.883	9.610	4.860	2.50
		8-10	0.72		0.998	9.200	4.040	2.50
		10-12	0.72		0.782	13.00	9.010	2.50
		12-14	0.71		0.716	6.190	4.020	2.59
		14-16	0.66		0.716	7.400	4.420	2.82
		16-18	0.61		0.707	17.500	14.600	3.28
		20-22	0.55		0.931	8.210	5.950	4.55
		22-24	0.53		2.120	15.200	9.740	5.07
		24-26	0.49	0.634	2.390	3.060	1.230	5.64
		26-28	0.48		3.010	21.400	14.400	6.26
		28-30	0.53		4.440	35.300	24.200	6.27
		30-32	0.51		4.660	77.100	53.600	7.02
		32-34	0.53	0.512	18.400	148.000	88.300	8.44
		34-36	0.54		10.400	85.500	46.100	6.86
		36-38	0.55		8.100	72.200	45.500	6.37
		38-40	0.56		6.540	48.300	31.200	6.02
		40-42	0.69		5.760	51.800	33.900	5.07
		42-44	0.94		3.230	45.300	30.700	4.32
		44-46	1.11	0.732	1.910	22.900	16.200	3.54
552	146-B1	0-4	0.48		0.623	6.720	5.550	4.11
		4-8	0.52	0.500	0.702	7.280	6.270	4.68
		8-12	0.50		1.610	18.100	15.200	6.11
		12-16	0.76	0.630	3.730	43.600	34.000	5.07
		16-20	1.03		0.593	7.390	5.420	2.16
		20-24	1.05	1.040	0.100	1.310	0.864	1.33
553	130-B1	0-4	0.68		0.698	5.080	4.150	3.10
		4-8	1.03	0.855	0.646	4.090	3.300	2.11
		8-12	1.15		0.251	1.580	1.220	1.46
		12-16	1.22	1.185	0.221	1.450	1.130	1.56

Station	Core No.	Increment (cm)	Dry density (g/cc)	Dry ave. density (g/cc)	Total PCB (ppm)	Total DDT (ppm)	p,p-DDE (ppm)	TOC (%)
554	125-B2	0-2	0.45		0.114	0.856	0.531	0.64
		2-4	0.86	0.655	0.110	0.854	0.539	0.69
		4-6	1.26		0.155	1.190	0.726	0.53
		6-8	1.37		0.117	1.020	0.593	0.88
		8-10	1.50	1.377	0.115	0.936	0.521	0.69
		10-13	1.61		0.057	0.461	0.229	0.35
		13-16	1.69		0.055	0.366	0.193	0.45
		16-20	1.64		0.091	0.454	0.258	0.81
		20-24	1.57		0.211	2.770	0.719	0.51
		24-28	1.50		0.190	1.800	0.389	0.95
		28-32	1.52	1.588	0.136	1.300	0.292	0.75
		32-36	1.18		0.073	0.729	0.222	0.95
		36-39	0.87	1.025	0.097	0.749	0.241	0.24
555	132-B1	0-2	1.09		0.278	4.500	3.630	0.90
		2-4	1.14		0.249	2.280	1.460	0.98
		4-6	1.10		0.253	2.380	1.580	0.86
		6-8	1.16		0.296	2.970	2.000	1.11
		8-10	1.21		0.299	3.470	2.630	1.18
		10-12	1.14		0.217	1.680	0.713	0.99
		12-14	1.03		0.245	2.370	1.340	1.02
		14-16	1.05		0.306	2.650	1.730	1.12
		18-20	1.13		0.357	3.280	2.140	1.26
		20-22	1.16		0.348	4.81	2.890	1.36
		22-24	1.14		0.342	3.850	2.680	1.44
		24-26	1.16		0.366	3.930	2.910	1.32
		26-28	1.15		0.374	3.570	2.430	1.54
		28-30	1.16		0.420	4.250	2.020	1.53
		30-32	1.15		0.428	3.790	2.540	1.42
		32-34	1.14		0.443	3.640	2.360	1.41
		34-36	1.11		0.604	4.980	3.330	1.52
		36-38	1.06		0.564	4.660	3.010	1.66
		38-40	1.06	1.123	0.514	4.700	2.760	1.66
556	131 -W1	0-2	0.59		1.360	9.630	6.070	2.75
		2-4	0.60	0.595	1.290	9.700	6.510	3.22
		4-6	0.62		1.520	17.000	12.900	3.23
		8-10	0.68		1.450	9.770	6.590	3.25
		10-12	0.72		1.330	17.200	13.700	3.60
		12-14	0.74		1.100	14.700	11.000	3.83
		14-16	0.69		1.430	14.100	10.400	4.38
		16-18	0.65		1.180	9.700	6.760	4.65
		18-20	0.66		1.510	15.100	11.000	4.53
		20-22	0.69	0.681	1.260	10.900	7.920	4.55
		22-24	0.69		2.770	21.700	14.800	5.33
		24-26	0.69	0.690	4.030	26.000	17.400	6.17

Station	Core No.	Increment (cm)	Dry density (g/cc)	Dry ave. density (g/cc)	Total PCB (ppm)	Total DDT (ppm)	p,p-DDE (ppm)	TOC (%)
556	141 -W1	0-2	0.57		1.070	9.960	6.770	3.07
		2-4	0.64		1.660	12.500	8.580	2.97
		4-6	0.63		1.020	9.270	5.700	2.71
		6-8	0.63		1.160	10.200	6.760	3.11
		8-10	0.66	0.626	1.310	11.200	7.440	3.48
		10-12	0.75		1.400	12.300	7.920	1.84
		12-14	0.79		0.902	12.400	9.79	2.70
		14-16	0.76		0.932	9.850	6.730	2.56
		16-18	0.75		1.410	14.900	10.000	3.03
		18-20	0.74		1.690	17.200	11.500	3.13
		20-22						3.29
		20-22	0.73		0.830	12.200	8.590	3.13
		22-24	0.66	0.740	0.916	9.100	5.910	318
		26-28			1.980	18.200	11.300	4.07
		28-30	0.55		2.240	18.800	12.000	4.47
		30-32	0.46		2.140	18.800	11.800	4.68
		32-34	0.46	0.490	3.480	31.700	19.700	5.33
556	147-B3	0-2	0.63		1.550	16.000	11.350	1.81
		2-4	0.63		1.240	14.700	10.800	2.96
		4-6	0.71		1.290	9.420	6.220	3.34
		6-8	0.78		1.740	11.400	7.440	3.24
		8-10	0.74		1.690	12.300	8.190	2.32
		10-12	0.74		1.440	12.900	8.240	2.87
		12-14	0.74		1.610	17.900	11.400	3.23
		14-16	0.68		1.250	16.000	11.000	3.30
		16-18	0.61		1.140	17.300	11.900	3.36
		18-20	0.56		0.866	12.400	8.700	3.39
		20-22	0.54	0.669	1.450	13.500	9.340	4.12
		22-24	0.53		1.540	21.600	15.600	4.54
		24-26	0.57		2.010	29.800	21.500	5.37
		26-28	0.53		2.920	43.900	29.700	5.92
		28-30	1.08		4.850	28.300	16.800	4.33
		30-32	0.57		5.240	28.700	17.700	5.99
		32-34	0.48		7.60	38.800	27.800	7.82
		34-36	0.50	0.609	9.030	36.600	24.500	6.73
		36-38	0.53		14.700	77.800	41.400	7.64
		38-40	0.54		14.500	230.000	156.000	5.72
		40-42	0.55		19.900	253.000	180.000	8.69
		42-44	0.58	0.550	10.800	201.000	141.000	7.06

Station	Core No.	Increment (cm)	Dry density (g/cc)	Dry ave. density (g/cc)	Total PCB (ppm)	Total DDT (ppm)	p,p-DDE (ppm)	TOC (%)
556	157-W1	0-2	0.62		0.972	8.250	5.560	2.67
		2-4	0.67		1.380	11.000	7.140	3.33
		4-6	0.67		1.370	10.700	7.120	3.04
		6-8	0.67		1.470	11.200	7.440	3.26
		8-10	0.68		1.160	6.960	4.380	3.36
		10-12	0.69		1.570	9.560	6.340	3.16
		12-14	0.71		1.380	12.700	8.190	3.46
		14-16	0.70		1.320	11.1	7.680	3.26
		16-18	0.70		1.310	11.200	7.540	3.34
		18-20	0.65		1.230	11.900	7.990	3.12
		20-22	0.62		1.130	11.900	7.400	3.40
		22-24	0.63		1.550	14.400	8.870	4.32
		24-26	0.60		1.610	14.300	9.820	4.58
		26-28	0.58		1.640	13.800	9.810	5.09
		28-30	0.53	0.648	2.520	16.800	9.160	5.34
		30-32	0.52		2.910	25.000	16.500	5.31
		32-34	0.53	0.525	3.400	25.900	17.700	5.50
557	127-B1	0-2	0.35		1.160	12.200	8.690	2.62
		2-4	0.52		0.952	10.400	7.000	3.97
		4-6	0.53		1.060	7.710	5.500	4.02
		6-8	0.53		1.090	7.580	5.370	4.00
		8-10	0.50		1.150	9.210	6.480	4.45
		10-12	0.48		1.370	10.400	7.400	4.41
		12-14	0.47	0.483	1.800	18.500	12.900	5.30
		14-16	0.45		3.940	37.400	24.300	6.83
		16-18	0.42		4.700	41.900	28.700	6.81
		18-20	0.39		6.980	32.000	22.000	7.24
		20-22	0.41		9.820	46.400	28.400	7.22
		22-24	0.44		10.500	8.000	66.600	7.60
		24-26	0.47		12.600	66.900	43.200	6.79
		26-28	0.56		11.600	78.500	47.900	6.48
		28-30	0.67	0.476	6.590	81.400	55.100	5.45
		30-32	0.99		2.660	29.800	20.500	3.85
		32-34	1.06		1.850	16.200	11.800	2.36
		34-38	0.37	0.807	0.266	2.130	1.450	2.12

Station	Core No.	Increment (cm)	Dry density (g/cc)	Dry ave. density (g/cc)	Total PCB (ppm)	Total DDT (ppm)	p,p-DDE (ppm)	TOC (%)
559	136-B1	0-2	0.43		0.348	2.100	1.400	3.49
		2-4	0.46	0.445	0.276	1.730	1.160	3.66
		4-6	0.49	0.490	0.687	46.300	44.900	3.73
		6-8	0.51		0.733	5.900	4.08	4.04
		8-10	0.56		0.658	5.700	3.470	4.00
		10-12	0.55		0.677	4.840	3.660	3.90
		12-14	0.58	0.550	1.080	7.990	6.090	4.40
		14-16	0.74		1.730	13.700	10.000	4.41
		16-18	0.85	0.795	1.320	15.6	6.700	2.82
		18-20	0.84	0.840	0.217	2.020	1.080	1.90
563	128-B1	0-4	1.21		0.050	0.655	0.410	0.52
		4-8	1.48		0.047	0.603	0.369	1.44
		8-12	1.57		0.027	0.286	0.217	0.43
		12-16	1.44		0.029	0.348	0.210	0.33
		16-20	1.37		0.048	0.548	0.261	0.65
		20-24	1.40		0.027	0.268	0.133	0.50
		24-28	1.43		0.055	0.659	0.331	1.11
		28-32	1.43	1.416	0.035	0.478	0.235	0.44
564	171-B1	0-2	0.65	0.650	1.800	27.100	20.200	2.24
		2-4	0.72		1.350	16.8	9.360	3.29
		2-4	0.72		1.200	13.800	8.570	3.29
		4-6	0.75		1.860	16.000	8.450	3.53
		6-8	0.74		1.680	22.400	15.200	3.78
		8-10	0.74		1.340	12.700	8.740	3.60
		10-12	0.72		1.300	12.200	8.570	3.45
		12- 14	0.70		1.290	13.900	7.380	4.22
		14-16	0.68		1.490	14.300	11.100	4.57
		16-18	0.68		1.360	12.800	9.210	5.02
		18-20	0.66	0.711	1.870	14.100	9.820	5.77
		20-22	0.60		2.940	20.400	13.800	6.39
		22-24	0.58		3.420	23.100	16.200	6.60
		24-26	0.59		3.890	26.300	17.800	5.73
		26-28	0.53		4.880	43.500	26.900	6.14
		28-30	0.49	0.558	9.250	50.300	35.400	8.18
		30-32	0.46		17.400	114.000	81.700	9.04
		32-34	0.46		20.600	164.000	110.000	9.61
		34-36	0.50		20.300	200.000	126.000	9.71
		36-38	0.49		18.400	181.000	108.000	9.35
		38-40	0.47	0.476	13.100	164.000	108.000	9.07

Station	Core No.	Increment (cm)	Dry density (g/cc)	Dry ave. density (g/cc)	Total PCB (ppm)	Total DDT (ppm)	p,p-DDE (ppm)	TOC (%)
566	122-B1	0-4	0.55	0.550	0.474	5.890	4.590	3.64
		4-8	0.66	0.660	1.940	16.100	11.300	5.55
		8-12	1.01		0.221	2.740	1.780	2.70
		12-16	1.32		0.086	1.010	0.718	0.86
		16-20	1.55		0.019	0.243	0.176	0.90
		20-24	1.52	1.350	NR	0.066	0.056	0.45
570	121-B1	0-4	0.72		0.422	3.580	2.130	2.14
		4-8	0.60		0.542	4.130	2.550	3.84
		8-12	0.56	0.627	1.130	8.880	6.700	4.54
		12-16	0.55		3.680	19.100	12.200	5.27
		16-20	0.59		3.340	18.100	11.000	5.71
		20-24	0.70		1.760	11.700	7.070	4.31
		24-28	1.13	0.742	0.981	8.700	6.090	2.41
		28-32	1.27		0.204	1.660	0.978	1.16
		32-36	1.31	1.290	0.038	0.320	0.207	0.83
571	117-B4	0-4	0.62	0.620	1.160	14.600	11.080	4.02
		4-8	0.65	0.650	2.890	33.800	25.90	5.07
		8-12	0.98	0.980	1.420	19.000	12.600	2.69
		12-16	1.20	1.200	0.415	6.230	4.420	1.40
		16-20	1.25	1.250	0.111	1.130	0.757	1.05
572	155-B2	0-4	0.52	0.520	0.910	14.900	11.100	3.52
		4-8	0.53		0.556	6.840	5.750	2.43
		8-12	0.43		0.456	3.910	3.100	3.31
		12-16	0.46	0.473	0.757	6.440	4.990	3.60
		16-20	0.51		0.945	15.600	11.300	3.69
		20-24	0.54	0.525	0.772	15.200	10.800	3.19
		24-28	0.62	0.620	0.325	4.930	3.410	1.69
		28-32	0.87	0.870	0.113	8.020	0.692	1.57
		32-36	1.00		NR	0.301	0.188	1.31
		36-40	1.02	1.010	NR	0.047	0.033	1.22

Station	Core No.	Increment (cm)	Dry density (g/cc)	Dry ave. density (g/cc)	Total PCB (ppm)	Total DDT (ppm)	p,p-DDE (ppm)	TOC (%)
574	153 B1	0-4	0.80	0.800	1.300	7.010	3.280	2.17
		4- 8	0.69		2.190	24.400	8.780	6.31
		8-12	0.58	0.635	7.610	54.900	21.600	7.46
		12-16	0.65	0.650	5.890	97.800	33.000	3.73
		16-20	0.72		4.120	49.100	30.000	5.15
		20-24	1.01	0.865	1.830	21.300	11.500	4.29
		24-28	1.33		0.712	4.130	0.731	1.94
		28-32	1.30		0.076	0.744	0.448	0.84
		32-36	1.21	1.280	0.425	3.360	2.270	0.81
577	120-B1	0-4	0.93		0.317	3.400	2.620	1.35
		4-8	0.87	0.900	0.170	1.050	0.836	2.64
		8-12	0.84		1.470	9.840	7.700	3.26
		12-16	0.96	0.900	1.290	9.920	7.600	2.40
		16-20	1.35		0.257	2.260	1.700	0.91
		20-24	1.44		0.104	0.732	0.496	0.68
		24-28	1.45	1.413	0.114	1.150	0.737	0.68
581	137-B1	6-2	0.59		0.483	2.000	1.380	2.82
		2-4	0.64		0.629	4.580	3.490	3.10
		4-6	0.74	0.657	0.473	3.93	2.890	2.94
		6-8	0.80		0.539	4.380	3.100	2.99
		8-10	0.83		0.652	6.830	5.220	2.78
		10-12	0.94		0.344	3.560	2.630	2.22
		12-14	0.95		0.169	1.850	1.280	1.76
		14-16	0.94		0.085	1.000	0.546	1.59
		16-18	0.94	0.900	NR	0.166	0.112	1.49
583	138-B2	0-4	0.43		0.339	5.630	4.910	3.30
		4-8	0.52	0.475	0.609	8.610	7.320	3.61
584	139-B2	0-4	0.51		0.296	2.390	1.740	2.84
		4-8	0.64	0.575	0.552	5.730	3.930	2.84